Grade Eight Focus on Physical Sciences

Students in grade eight study topics in physical sciences, such as motion, forces, and the structure of matter, by using a quantitative, mathematically based approach similar to the procedures they will use in high school. Earth, the solar system, chemical reactions, the chemistry of biological processes, the periodic table, and density and buoyancy are additional topics that will be treated with increased mathematical rigor, again in anticipation of high school courses. Students should begin to grasp four concepts that help to unify physical sciences: force and energy; the laws of conservation; atoms, molecules, and the atomic theory; and kinetic theory. Those concepts serve as important organizers that will be required as students continue to learn science. Although much of the science called for in the standards is considered "classical" physics and chemistry, it should provide a powerful basis for understanding modern science and serve students as well as adults.

Mastery of the eighth-grade physical sciences content will greatly enhance the ability of students to succeed in high school science classes. Modern molecular biology and earth sciences, as well as chemistry and physics, require that students have a good understanding of the basics of physical sciences.

STANDARD SET 1. Motion

Aristotle wrote that a force is required to keep a body moving. Everyday experience seems to confirm this misconception. For two thousand years Aristotle's description of motion was accepted without question. Then an experiment by Galileo resulted in the discovery of friction. Galileo's experimental approach to investigating Nature helped to establish modern science and led to the invention of calculus and Newton's laws of motion. Four centuries after Galileo the knowledge of motion enables scientists to predict and control the paths of distant spacecraft with great accuracy.

There are many types of motion: straight line, circular, back and forth, free-fall, projectile, orbital, and so on. This standard set concerns itself with the motion of a body traveling either at a constant speed or with a varying speed that is represented by an average value.

1. The velocity of an object is the rate of change of its position. As a basis for understanding this concept:

a. *Students know* position is defined in relation to some choice of a standard reference point and a set of reference directions.

The position of a person or object must be described in relation to a standard reference point. For example, the position of a bicycle may be in front of the flagpole or behind the flagpole. The flagpole is the reference point, and *in front of* and *behind* are the reference directions. A reference point is usually called the *origin,* and position can be expressed as a distance from the reference point together with a plus (+) or minus (–) sign that may stand for *in front of* and *behind, away from* and *toward, right* and *left,* or one of any other pair of convenient, opposing directions from the reference point.

The idea of measuring positions, distances, and directions in relation to a standard reference point may be introduced by using metersticks (or rulers). The students are directed to call the 50 cm mark (or some other convenient mark) the reference point. A position of –10 cm would be 10 cm to the left of the standard reference point; a position of +5 cm would be 5 cm to the right of the standard reference point. The teacher may call out various positive and negative position values, and the students should point to that location on the ruler. In particular, students can experience the fact that although moving in a positive direction (to the right) when going from –10 cm to –6 cm, they still end up pointing to a spot that is to the left of the origin. Students in grade eight should be able to track the motion of objects in a two-dimensional (x, y) coordinate system. For example, both x and y may represent distances along the coordinate axes, or the value of y might represent the distance traveled and x might represent elapsed time.

1. b. *Students know* that average speed is the total distance traveled divided by the total time elapsed and that the speed of an object along the path traveled can vary.

Speed is how fast something is moving in relation to some reference point without regard to the direction. It is calculated by dividing the distance traveled by the elapsed time. In the next standard students should learn to use the International System of Units (a modernized version of the metric system) to measure distance in meters (m) and time intervals in seconds (s). Thus a car traveling 120 kilometers in two hours is traveling at a speed of 60 km/hr. (In everyday units speed is measured in miles per hour. In the school laboratory it may be more convenient to use centimeters instead of meters for measuring distances and seconds for measuring time; therefore, speed would be expressed in centimeters per second [cm/s].) The speed of a spacecraft may be measured by how long it takes to orbit Earth and the length of that orbit. Sometimes the speed of an object remains constant while it is being observed, but usually the speed of a vehicle changes during a trip. Students should be taught to recognize that the average speed of a vehicle is calculated by dividing the total distance traveled by the length of time to complete the entire trip. With several stops a trip of 100 miles from town A to town B may take four hours. The average speed is 100 miles ÷ 4 hours = 25 miles per hour (mph) even though at times the car may have had a speedometer reading of 55 mph.

Students can measure the entire distance that a toy vehicle or ball travels across the floor or tabletop after it is released from the top of an inclined ramp (the standard reference point). They can also measure the time elapsed during the trip. The average speed can then be calculated by dividing the distance traveled (from the standard reference point) by the elapsed time. More than one student may be assigned to measure the times and distances so that duplicate data sets are created. The teacher may explore with the students why the data sets are not exactly the same and help them evaluate the accuracy and reproducibility of the experiment. The object's speed may be observed to change during the trip: it travels faster down the ramp because of gravity and slows down as it travels across the floor or tabletop because of friction. What is being calculated by $v = d/t$ (where v is the average speed, d is the total distance traveled, and t is the elapsed time) is the average speed for the entire trip as though the object were to travel at a constant speed. Students may change one of the conditions, such as the height of the ramp, to see how that affects the average speed. Or students do not have to wait for the object to stop; they may measure the elapsed time for the object to roll from the top of the ramp to any point along the path, before the object stops, to obtain the average speed between the measurement points.

1. c. *Students know* how to solve problems involving distance, time, and average speed.

Problems related to this standard may be solved by using the traditional mathematics formula: $d = rt$. The d represents the total distance traveled, r stands for rate (or speed) and represents either the constant speed (if the speed is constant) or average speed (if it varies), and t represents the time taken for the trip. Given any two of these quantities, students can calculate the third quantity: $d = rt$, $t = d/r$, $r = d/t$. Students may be given information involving d, r, or t for different segments of a real or hypothetical trip and asked to use the formula $d = rt$ to solve for the missing information. To avoid confusion later, teachers may introduce the symbol v for speed instead of r once students are familiar with this type of problem. (When the vector nature of *velocity* needs to be introduced, the v will be written in boldfaced type, $\mathbf{v}$, as will other vector quantities in the framework.)

1. d. *Students know* the velocity of an object must be described by specifying both the direction and the speed of the object.

The word *velocity* has a special meaning in science. An air traffic controller needs to know both the speed and the direction of an aircraft (as well as its position), not just the speed. Measurable quantities that require both the magnitude (sometimes the term *size* is used) and direction are called *vector quantities.* Displacement, velocity, acceleration, and force are all vector quantities and will be introduced in grade eight by using only one dimension or specified pathway. An arrow pointing in the direction of motion usually represents the velocity of an object. The length of the arrow is proportional to how fast the object is going (the speed). Students demonstrate mastery of this standard by knowing, without prompting, that they must specify both speed and direction when asked to describe an object's velocity.

1. e. *Students know* changes in velocity may be due to changes in speed, direction, or both.

Since velocity is a vector quantity, the velocity of an object is determined by both the speed and direction in which the object is traveling. Changing the speed of an object changes its velocity; changing the direction in which an object is traveling also changes the velocity. A change in either speed or direction (or both) will, by definition, change the velocity. (Although the term is not included in this standard set, the rate at which velocity changes with time is called *acceleration.* When a car speeds up or slows down, it undergoes acceleration. When a car rounds a curve maintaining the same speed, it also undergoes acceleration because it changes direction.)

The important idea is that a change in the speed of the object, the direction of the moving object, or both is a change in velocity. Students may easily understand that a change in the speed of an object causes a change in the velocity; it may be less obvious to students that a change in the direction of an object, with no change in the speed, also changes the velocity of the object. Students need to recognize that spinning, curving soccer balls, baseballs, or Ping-Pong balls may maintain a nearly constant speed through the air but change velocity because they change direction. Of course, an object may undergo a change in velocity in which both the direction and the speed change; for example, when a driver applies the brakes while going around a curve.

In the next standard set, students will learn that changes in velocity are always related to one or more forces acting on the object. Students learn to find and identify forces and to determine the direction of each force's action. Being able to recognize velocity changes of magnitude and direction is key to observing and characterizing forces.

1. f. *Students know* how to interpret graphs of position versus time and graphs of speed versus time for motion in a single direction.

Students are required to apply the graphing skills they learned in lower grades to the plotting and interpretation of graphs of distance, location, and position (d) versus time (t) and of speed (v) versus time (t) for motion in a single direction. A major conceptual difference from the graphing skills learned in mathematics is that the two axes will no longer be number lines with no units. What must be explicitly addressed in dealing with motion graphs is the plotting of locations in distance units (e.g., meters, centimeters, miles) on the vertical axis and plotting of time in time units (seconds, minutes, hours) on the horizontal axis.

In plotting position versus time, students should learn that the vertical axis represents distances away from an origin either in the positive (+) or negative (–) direction. The horizontal axis represents time. Every data point lying on the horizontal axis is "at the origin" because its distance value is zero. Given a graph of position versus time, students should be able to generate a table and calculate average speeds for any time interval ($v = d/t$). If the graph of position versus time is a straight line, the speed is constant; students should be able to find the slope and know that the slope of the line is numerically equal to the value of the speed in units corresponding to the labels of the axes.

Students should know that a graph of speed versus time consisting of a horizontal line represents an object traveling at a constant speed, and they should be able to use $d = rt$ to calculate the distance (d) traveled during a time interval (t). Students should know that a graph of speed versus time that is not a horizontal line indicates the speed is changing.

STANDARD SET 2. Forces

The concept of force is central to the study of all natural phenomena that involve some kind of interaction between two or more objects regardless of whether visible motion occurs. For example, architects and civil engineers want their structures to stand firm against the forces of gravity, wind, and earthquakes. On the other hand, automotive engineers need to know how best to accelerate a car, brake it to a safe stop, and smoothly change its direction. Students need to know that balanced forces keep an object from changing its velocity and that changes in the velocities of objects are caused by unbalanced forces.

There are only four known fundamental forces: gravitational forces, electromagnetic forces, and two nuclear forces known as the strong and the weak forces. Gravitational force is the attraction all objects with mass have for one another. The common experience of gravity on Earth is only one example; the other forces of pushing and pulling are elastic forces caused by electromagnetic interactions between atoms and molecules being pushed together or pulled apart. The large, repulsive electrical forces between the positively charged protons in the nucleus of an atom are balanced against the stronger, attractive nuclear forces that hold the atom together.

Students learned in grade two that the way to change how something is moving is to give it a push or a pull (e.g., apply a force). In grade four the study of magnets, compasses, and static electricity gave students experience with electromagnetic forces. In grade seven students learned about motion and forces, which involved comparing bones, muscles, and joints in the body to machines.

2. Unbalanced forces cause changes in velocity. As a basis for understanding this concept:

a. *Students know* a force has both direction and magnitude.

Forces are pushes or pulls and, like velocity, are vector quantities described by the magnitude and the direction of a force. As noted in Standard 1.d, the direction and strength of a force may be indicated graphically by using an arrow. The length of the arrow is proportional to the strength of the force, and the arrow points in the direction of the force's application.

The simplest case to consider is that of forces acting along one line, such as to the left or to the right. These colinear forces act either in the positive direction and are represented as positive quantities or in the negative direction and are represented as negative quantities.

A worthwhile activity is to have the students pull objects across level surfaces to measure the forces of friction. Different surfaces, because of varying roughness or different types of material, will exert different forces of friction on an object being dragged across them. If an object is pulled at a constant speed across a level surface, the force applied is just equal and opposite to the force of friction. If the force applied is greater than the force of friction, the object will slide easily. If the force applied is less than the force of friction, the object will drag. If the force applied is zero, the object will slow down and stop more quickly under the influence of the force of friction alone. Students can obtain data by using a spring scale to measure the force and compare different objects on different surfaces.

2. b. *Students know* when an object is subject to two or more forces at once, the result is the cumulative effect of all the forces.

Forces acting on an object along the same line at the same time are calculated by using algebra. For example, a force of 5 newtons acting in the positive direction (+5 N) and a force of 7 newtons acting in the negative direction (–7 N) will result in an unbalanced force of 2 newtons acting in the negative direction (–2 N). A force of one newton is close to the weight of half a stick of butter or of a small apple. (In high school physics, students will learn that forces acting at different angles on an object can be broken down into components along the *x* axis, *y* axis, and *z* axis and that these components can also be calculated algebraically.)

2. c. *Students know* when the forces on an object are balanced, the motion of the object does not change.

When several forces act simultaneously on an object, they may amount to zero, meaning there is no net force on the object and the motion of the object does not change. For example, a force of 10 newtons acting to the right (+10 N) and a second force of 10 newtons acting to the left (–10 N) amount to zero, meaning there will be no change in the velocity of the object. Sometimes an object acted on by balanced forces is at rest and remains at rest. In a tug of war in which opposing sides are pulling a rope with equal force, the rope does not move.

Sometimes a moving object is acted on by balanced forces and continues to move at the same velocity. For example, pushing a book straight across a table at a constant velocity requires force. The book does not speed up, slow down, or change direction; therefore, one must conclude a frictional force is pushing back on the book. Many people have the misconception that a force is necessary for an object to maintain a constant velocity; they overlook the opposing force of friction. Identifying and analyzing the forces acting on a sliding object by observing its velocity can help students develop their observation and analysis of frictional forces.

If the motion (or velocity) of an object is not changing, one may conclude that all the forces must be balanced. There are two equal and opposing vertical forces (weight down and table up) acting on the book as well as two equal and opposing horizontal forces (sliding push and friction): a total of four forces.

2. d. *Students know* how to identify separately the two or more forces that are acting on a single static object, including gravity, elastic forces due to tension or compression in matter, and friction.

The force of gravity pulls objects toward the center of the earth. This force of gravity is commonly called the *weight* of the object. If an object is dropped, the force of gravity alone causes the velocity of the object to increase rapidly in the down direction. But when a single object is at rest, such as a book on a table, the table must be supplying a balancing upward force (an elastic force of compression caused by the compacting of the molecules of the table). When an object, such as a yo-yo, is observed hanging motionless from a string, the string must be supplying a balancing upward force—an elastic force of tension as its molecules are stretched apart. A student may push gently on a book to move it horizontally across the table, but the book does not move. The horizontal push cannot be the only acting force. A second force pushes back to keep the book at rest. This opposing force is the friction between the molecules in the surface of the book and the surface of the table.

Resting a book on a meterstick spanning the gap between two student desks usually causes the meterstick to sag, showing that the meterstick flexes until the upward force from its elastic distortion is sufficient to support the book. Resting a book on a soft, dry sponge or spring might also show how elastic forces support the book against the downward pull of gravity.

2. e . *Students know* that when the forces on an object are unbalanced, the object will change its velocity (that is, it will speed up, slow down, or change direction).

When an unbalanced force acts on an object initially at rest, the object moves in the direction of the applied force. If an object is already in motion, for example, traveling to the right, and an unbalanced force acts to the right, the object will speed up. An object traveling to the right acted on by an unbalanced force to the left will slow down; if the unbalanced force continues to act, the object may slow to a stop and even begin to move faster in the opposite direction. If an unbalanced force acts in a direction perpendicular to the direction the object is moving, the force will deflect the object from its path, changing its direction but not its speed along the curved path. Any force that acts in such a direction (for example, the force of the road on the tires of a car) is called a *centripetal force.* This force is directed to the center of the orbit. Finally, an unbalanced force acting at an angle to the path may affect both the speed and the direction of the object.

Students should be able to predict changes in velocity if forces are shown to be acting on an object and be able to identify that an unbalanced force is acting on an object if they observe a change in its velocity. Students may not be able to explain fully the cause of the unbalanced forces acting on the baseball pitcher's curve ball or on the path of a spinning soccer ball, but they can state that there is a force acting perpendicular to the path of the ball.

2. f. *Students know* the greater the mass of an object, the more force is needed to achieve the same rate of change in motion.

When the forces acting on an object are unbalanced, the velocity of the object must change by increasing speed, decreasing speed, or altering direction. This principle also means that if an object is observed to speed up, slow down, or change direction, an unbalanced force must be acting on it. The rate of change of velocity is called *acceleration.* At the high school level, students will learn to solve problems by using Newton's second law of motion, which states that the acceleration of an object is directly proportional to the force applied to the object and inversely proportional to its mass. For now students should learn to recognize acceleration (or deceleration) and should be able to state the direction and relative magnitude of the force that is the cause of the acceleration.

When an unbalanced force acts on an object, the velocity of the object can change slowly or rapidly. How fast the velocity of the object changes, that is, the rate of change in velocity with time (called acceleration), depends on two things: the size of the unbalanced force acting on the object and the mass of the object. The larger the unbalanced force, the faster the velocity of the object changes, but the greater the mass of the object, the slower the velocity changes. Quantitatively, the acceleration of an object may be predicted by dividing the net force acting on the object by the mass of the object.

Often high school students learn to solve problems involving force without clearly relating the physical circumstances to the word problem presented. It is important to teach students in grade eight to identify mass, velocity, acceleration, and forces and to analyze how those factors relate to one another in the physical system being studied. The ability to make qualitative predictions about what will happen next in these situations is the key to successful problem solving that all scientists use before starting a calculation. Once the correct qualitative prediction is envisioned, a numerical solution is more likely to be correct. For example, students might be told that an opposing force is applied to an object being pushed along the ground. Given all the numbers needed to calculate the object's final velocity, the students should be able to predict correctly whether the object could slow down, come to a stop, or even start moving backward before they solve the problem numerically.

2. g. *Students know* the role of gravity in forming and maintaining the shapes of planets, stars, and the solar system.

Gravity, an attractive force between masses, is responsible for forming the Sun, the planets, and the moons in the solar system into their spherical shapes and for holding the system together. It is also responsible for internal pressures in the Sun, Earth and other planets, and the atmosphere. Newton asked himself whether the force that causes objects to fall to Earth could extend to the Moon. Newton knew that the Moon should travel in a straight line (getting farther and farther from Earth) unless a force was acting on it to change its direction into a circular path.

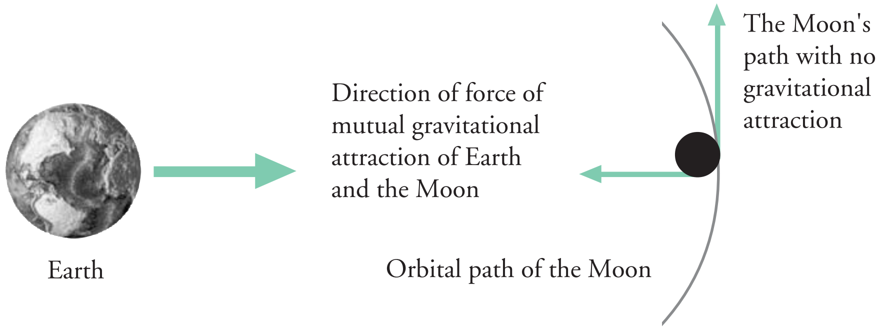


Fig.1. Effect of Gravity on the Moon's Path

He worked out the mathematics that convinced him that the force between all massive objects is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centers. This relationship was then extended to explain the motion of Earth and other planets about the Sun.

Initially, the universe consisted of light elements, such as hydrogen, helium, and lithium, distributed in space. The attraction of every particle of matter for every other particle of matter caused the stars to form, making possible the "stuff" of the universe. As gravity is the fundamental force responsible for the formation and motion of stars and of the clusters of stars called galaxies, it controls the size and shape of the universe.

STANDARD SET 3. Structure of Matter

There is no disagreement about the importance of understanding the structure of matter. Richard Feynman, a famous Nobel prize-winning physicist, has said:

> If, in some cataclysm, all scientific knowledge were to be destroyed and only one sentence passed on to the next generation of creatures, what statement would contain the most information in the fewest words? I believe it is the atomic hypothesis (or atomic fact, or whatever you wish to call it) that all things are made of atoms—little particles that move around in perpetual motion attracting each other when they are a little distance apart, but repelling upon being squeezed into one another.[7]

Teachers should assess students' knowledge prior to instruction of this topic, as the atomic theory of matter may be very challenging to them. Students are expected to recall terms and definitions from earlier introductions to the concepts of atoms, molecules, and elements. Instruction should provide empirical evidence for the atomic theory, which will be useful for understanding science and crucial to the study of chemistry.

When students learn about the structure of matter, teachers should emphasize that the historical evidence for atoms was based largely on indirect measurements and inferences far removed from direct experience. Recently, instruments have been built that produce images of individual atoms, confirming what was inferred earlier as a result of overwhelming evidence from many scientific experiments. Most scientists come to know the atomic theory is true by repeatedly using the concepts and principles presented in the theory to explain observed properties and predict changes in matter.

3. Each of the more than 100 elements of matter has distinct properties and a distinct atomic structure. All forms of matter are composed of one or more of the elements. As a basis for understanding this concept:

a. *Students know* the structure of the atom and know it is composed of protons, neutrons, and electrons.

Shortly after British physicist Ernest Rutherford inferred the existence of atomic nuclei, the general idea emerged that atoms are mostly empty space with a tiny, massive nucleus at the center containing positively charged protons and neutral neutrons. This nucleus is surrounded by tiny, negatively charged electrons, each with about 1/2,000 the mass of a proton or neutron. Danish physicist Niels Bohr developed a model of the hydrogen atom to explain its visible spectrum. At the high school level, the chemistry standards require students to know the historical importance of this model. Bohr's model succeeded in predicting the spectrum of light emitted by hydrogen atoms and is therefore the acknowledged starting point for understanding atomic structure. However, Bohr's "solar" model of the atom, diagrammed in most textbooks as showing electrons in circular orbits about the nucleus, is oversimplified. Rather than try to describe how the electrons in an atom are moving, teachers are better advised to help students develop a model of the atom in which each electron has definite energy. Students should know that the energy of each electron in an atom keeps it in motion around the positive nucleus to which it is attracted. The structure of multielectron atoms is understood in terms of electrons filling energy levels that define *orbitals.*

3. b. *Students know* that compounds are formed by combining two or more different elements and that compounds have properties that are different from their constituent elements.

The word *combining* implies bonding. Understanding the concepts of ionic and covalent bonding helps explain why some elements combine to form compounds and some do not. Atoms of different elements combine to form compounds; a compound may, and usually does, have chemical characteristics and physical properties that are different from those of its constituent elements. Examples and generalizations may be drawn from ionic compounds formed of metals and nonmetals and covalently bonded, organic compounds formed from carbon and other elements.

Students often learn to manipulate chemical equations without having a picture in their minds of physical reality at the atomic level. The ability to create such a picture is a useful skill that helps students keep track of all the atoms in the process. For example, the reaction of methane and oxygen to form carbon dioxide and water can be visualized by using models or drawing pictures of the atoms and molecules in the reactants. These molecules can then be rearranged into new products. (Make sure that all the atoms in the starting reactants are accounted for in the new products.) Instruction in this standard will help students understand that compounds are collections of two or more different kinds of atoms that are bonded together. Knowing exactly how the atoms are organized to form a molecule is not essential.

3. c. *Students know* atoms and molecules form solids by building up repeating patterns, such as the crystal structure of NaCl or long-chain polymers.

Crystals of table salt, the compound NaCl, have a regular, cubic structure in which sodium (Na^+) ions alternate with chlorine (Cl^-) ions in three-dimensional array with the atoms at the corner of cubes forming the lattice. In organic polymers, the carbon, hydrogen, sometimes oxygen, and nitrogen atoms combine to form long, repetitive, stringlike molecules.

Inexpensive models of molecules may be made by using colored gumdrops (held together by toothpicks) to represent molecules. Students identify the atoms that constitute the molecules by using a color-coded key relating the color of the gumdrop to an atom of an element. They learn that the shape of a molecule is important to its chemical and physical properties. At the high school level, students will be introduced to the idea that shape is determined mainly by the electron configuration that provides the most energy-stable system.

Students can also grow crystals from a solution and should understand that this process leads to the building up of atoms into a lattice. Students may begin the process by dissolving an excess of sodium chloride, sugar, or Epsom salts in water. Then they hang a string in the water and store the container in a place where it will be undisturbed while the water evaporates. Crystals will form on the string. Putting a small (seed) crystal tied to a piece of thread in the solution will accelerate the growth process. Books and kits (including chemicals, glassware, and instructions) on crystal growing are available commercially. Students can watch crystals grow on slides under a microscope. Some crystals display vivid colors when viewed between crossed sheets of polarizing material.

3. d. *Students know* the states of matter (solid, liquid, gas) depend on molecular motion.

All atoms, and subsequently all molecules, are in constant motion. For any given substance the relative freedom of motion of its atoms or molecules increases from solids to liquids to gases. When a thermometer is inserted into a substance and the temperature is measured, the average atomic or molecular energy of motion is being measured. The state of matter of a given substance therefore depends on the balance between the internal forces that would restrain the motion of the atoms or molecules and the random motions that are in opposition to those restraints.

The change in phases is evidence of various degrees of atomic and molecular motion. The conditions of temperature and pressure under which most materials change from solid to liquid or liquid to vapor (gas) or gas to plasma have been measured. Those properties are difficult to predict but are highly reproducible for different samples of the same material and can be used to identify substances. Some substances will go from solid to gas directly at one atmosphere pressure. Dry ice, which is frozen carbon dioxide, is an example. Chemistry handbooks contain the melting points (or freezing points) and boiling points (or condensation temperatures) of most materials usually under one atmosphere pressure. If the pressure is not one atmosphere, those temperatures change. Some substances have more than one stable solid phase at room temperature. Graphite, with its soft black texture and its hard, clear crystalline diamond atomic structure, represents the two solid phases of elemental carbon.

Water is another example of a substance that undergoes a change in atomic and molecular motion under extreme conditions of temperature and pressure. At one atmosphere pressure, ice forms when water is cooled below zero degrees Celsius (or 32 degrees Fahrenheit). Above the freezing point the average molecular energy of motion of the water molecules is just enough to overcome the attractive forces between the molecules. The water molecules thereby avoid being locked in place and remain liquid. At and below the freezing point, the water molecules become the solid, crystalline material called ice. When liquid water is heated to temperatures of 100 degrees Celsius, molecular motion increases until large groups of water molecules overcome the attractive forces between the molecules. At this point those energetic molecules form bubbles of steam, which are bubbles of gas made not of air but of water. The process in which bubbles of water vapor escape from liquid water is called *boiling.* Continued heating will change the liquid water entirely into vapor instead of raising the temperature of the water above 100 degrees Celsius.

3. e. *Students know* that in solids the atoms are closely locked in position and can only vibrate; in liquids the atoms and molecules are more loosely connected and can collide with and move past one another; and in gases the atoms and molecules are free to move independently, colliding frequently.

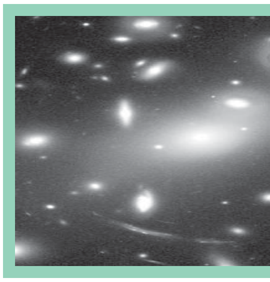
The atoms or molecules of a solid form a pattern that minimizes the structural energy of the solid consistent with the way in which the atoms or molecules attract at long distances but repel at short distances. The atoms or molecules vibrate about their equilibrium positions in this pattern. When raised above the melting temperature, the atoms or molecules acquire enough energy to slide past one another so that the material, now a liquid, can flow; the density of the liquid remains very close to that of the solid, demonstrating that in a solid or a liquid the atoms stay at about the same average distance.

If a single atom or molecule acquires enough energy, however, it can pull away from its neighbors and escape to become a molecule of a gas. Gas molecules move about freely and collide randomly with the walls of a container and with each other. The distance between molecules in a gas is much larger than that in a solid or a liquid, and this point may be emphasized when students study density.

3. f. *Students know* how to use the periodic table to identify elements in simple compounds.

The periodic table of elements is arranged horizontally in order of increasing atomic number (number of protons) and vertically in columns of elements with similar chemical properties. Students should learn to use the periodic table as a quick reference for associating the name and symbol of an element in compounds and ions. They should be able to find the atomic number and atomic weight of the element listed on the table. The periodic table is both a tool and an organized arrangement of the elements that reveals the underlying atomic structure of the atoms. This standard focuses on the table as a tool.

Every field of science uses the periodic table, and various forms of it exist. Astrophysicists may have a table that includes elemental abundances in the solar system. Physicists and engineers may use tables that include boiling and melting points or thermal and electrical conductivity of the elements. Chemists have tables that show the electron structures of the element. Students should be encouraged to refer to the periodic table as they study the properties of matter and learn about the atomic model.



STANDARD SET 4. Earth in the Solar System (Earth Sciences)

Students in grade eight are ready to tackle the larger picture of galaxies and astronomical distances. They are ready to study stars compared with and contrasted to the Sun and to learn in greater detail about the planets and other objects in the solar system. High school studies of earth sciences will include the dimension of time along with three-dimensional space in the study of astronomy.

4. The structure and composition of the universe can be learned from studying stars and galaxies and their evolution. As a basis for understanding this concept:

a. *Students know* galaxies are clusters of billions of stars and may have different shapes.

Stars are not uniformly distributed throughout the universe but are clustered by the billions in galaxies. Some of the fuzzy points of light in the sky that were originally thought to be stars are now known to be distant galaxies. Galaxies themselves appear to form clusters that are separated by vast expanses of empty space. As galaxies are discovered they are classified by their differing sizes and shapes. The most common shapes are spiral, elliptical, and irregular. Beautiful, full-color photographs of astronomical objects are available on the Internet, in library books, and in popular and professional journals. It may also interest students to know that astronomers have inferred the existence of planets orbiting some stars.

4. b. *Students know* that the Sun is one of many stars in the Milky Way galaxy and that stars may differ in size, temperature, and color.

The Sun is a star located on the rim of a typical spiral galaxy called the Milky Way and orbits the galactic center. In similar spiral galaxies this galactic center appears as a bulge of stars in the heart of the disk. The bright band of stars cutting across the night sky is the edge of the Milky Way as seen from the perspective of Earth, which lies within the disk of the galaxy. Stars vary greatly in size, temperature, and color. For the most part those variations are related to the stars' life cycles. Light from the Sun and other stars indicates that the Sun is a fairly typical star. It has a mass of about 2×10^{30} kg and an energy output, or luminosity, of about 4×10^{26} joules/sec. The surface temperature of the Sun is approximately 5,500 degrees Celsius, and the radius of the Sun is about 700 million meters. The surface temperature determines the yellow color of the light shining from the Sun. Red stars have cooler surface temperatures, and blue stars have hotter surface temperatures. To connect the surface temperature to the color of the Sun or of other stars, teachers should obtain a "black-body" temperature spectrum chart, which is typically found in high school and college textbooks.

4. c. *Students know* how to use astronomical units and light years as measures of distance between the Sun, stars, and Earth.

Distances between astronomical objects are enormous. Measurement units such as centimeters, meters, and kilometers used in the laboratory or on field trips are not useful for expressing those distances. Consequently, astronomers use other units to describe large distances. The astronomical unit (AU) is defined to be equal to the average distance from Earth to the Sun: 1 AU = 1.496×10^{11} meters. Distances between planets of the solar system are usually expressed in AU. For distances between stars and galaxies, even that large unit of length is not sufficient. Interstellar and intergalactic distances are expressed in terms of how far light travels in one year, the light year (ly): 1 ly = 9.462×10^{15} meters, or approximately 6 trillion miles. The most distant objects observed in the universe are estimated to be 10 to 15 billion light years from the solar system. Teachers need to help students become familiar with AUs by expressing the distance from the Sun to the planets in AUs instead of meters or miles. A good way to become familiar with the relative distances of the planets from the Sun is to lay out the solar system to scale on a length of cash register tape.

4. d. *Students know* that stars are the source of light for all bright objects in outer space and that the Moon and planets shine by reflected sunlight, not by their own light.

The energy from the Sun and other stars, seen as visible light, is caused by nuclear fusion reactions that occur deep inside the stars' cores. By carefully analyzing the spectrum of light from stars, scientists know that most stars are composed primarily of hydrogen, a smaller amount of helium, and much smaller amounts of all the other chemical elements. Most stars are born from the gravitational compression and heating of hydrogen gas. A fusion reaction results when hydrogen nuclei combine to form helium nuclei. This event releases energy and establishes a balance between the inward pull of gravity and the outward pressure of the fusion reaction products.

Ancient peoples observed that some objects in the night sky wandered about while other objects maintained fixed positions in relation to one another (i.e., the constellations). Those "wanderers" are the planets. Through careful observations of the planets' movements, scientists found that planets travel in nearly circular (slightly elliptical) orbits about the Sun.

Planets (and the Moon) do not generate the light that makes them visible, a fact that is demonstrated during eclipses of the Moon or by observation of the phases of the Moon and planets when a portion is shaded from the direct light of the Sun.

Various types of exploratory missions have yielded much information about the reflectivity, structure, and composition of the Moon and the planets. Those missions have included spacecraft flying by and orbiting those bodies, the soft landing of spacecraft fitted with instruments, and, of course, the visits of astronauts to the Moon.

4. e. *Students know* the appearance, general composition, relative position and size, and motion of objects in the solar system, including planets, planetary satellites, comets, and asteroids.

Nine planets are currently known in the solar system: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto. They vary greatly in size and appearance. For example, the mass of Earth is 6×10^{24} kg and the radius is 6.4×10^{6} m. Jupiter has more than 300 times the mass of Earth, and the radius is ten times larger. The planets also drastically vary in their distance from the Sun, period of revolution about the Sun, period of rotation about their own axis, tilt of their axis, composition, and appearance. The inner planets (Mercury, Venus, Earth, and Mars) tend to be relatively small and are composed primarily of rock. The outer planets (Jupiter, Saturn, Uranus, and Neptune) are generally much larger and are composed primarily of gas. Pluto is composed primarily of rock and is the smallest planet in the solar system.

All the planets are much smaller than the Sun. All objects are attracted toward one another gravitationally, and the strength of the gravitational force between them depends on their masses and the distance that separates them from one another and from the Sun. Before Newton formulated his laws of motion and the law of universal gravitational attraction, German astronomer Johannes Kepler deduced from astronomical observations three laws (Kepler's laws) that describe the motions of the planets.

Planets have smaller objects orbiting them called *satellites* or *moons.* Earth has one moon that completes an orbit once every 28 days (approximately). Mercury and Venus have no moons, but Jupiter and Saturn have many moons. Very small objects composed mostly of rock (asteroids) or the ice from condensed gases (comets) or both also orbit the Sun. The orbits of many asteroids are relatively circular and lie between the orbital paths of Mars and Jupiter (the asteroid belt). Some asteroids and all comets have highly elliptical orbits, causing them to range great distances from very close to the Sun to well beyond the orbit of Pluto.

Teachers should look for field trip opportunities for students to observe the night sky from an astronomical observatory or with the aid of a local astronomical society. A visit to a planetarium would be another way of observing the sky. If feasible, teachers should have students observe the motion of Jupiter's inner moons as well as the phases of Venus. Using resources in the library-media center, students can research related topics of interest.

STANDARD SET 5. Reactions

When substances react, the atoms involved in the reactants are rearranged, forming other products. Students have learned that the physical and chemical properties of the newly formed substances (products) are different from the physical and chemical properties of the original substances (reactants). Students in grade eight will learn that it is the underlying arrangement of the atoms in the reactants and products and the energy needed or released during the rearrangement process that explain chemical reactions. Understanding chemical reactions is essential because they constitute, directly or indirectly, a large portion of the discipline of chemistry.

Students need to be able to distinguish a chemical change from a physical change. In a physical change one or more physical properties of the material are altered, but the chemical composition (i.e., the arrangement of the atoms in molecules) remains the same. In a chemical change the atoms are rearranged to form new substances with different chemical and physical properties. Students must be familiar with the periodic table and the names and symbols of the chemical elements.

In grade one students are prepared for the idea of chemical reactions when they learn that the properties of substances can change when they are mixed, cooled, or heated. In grade three they learn that when two or more substances are combined, a new substance may be formed with properties that are different from those of the original materials. In grade five they learn that during chemical reactions, the atoms in the reactants rearrange to form products with different properties.

The study on reactions begun in grade eight will support future studies about conservation of matter and stoichiometry as well as work on acids, bases, and solutions. Students will go beyond studying reactions and their reactant/product relationships to work with the rates of reaction and chemical equilibrium. Students should be able to envision a chemical equation at the atomic and molecular levels. They should "see" the number of reactant atoms and molecules in the equation coming together and by some process rearranging into the correct number of atoms and molecules that form the products. This important conceptual skill helps students to keep track of all the atoms.

5. Chemical reactions are processes in which atoms are rearranged into different combinations of molecules. As a basis for understanding this concept:

a. *Students know* reactant atoms and molecules interact to form products with different chemical properties.

This standard focuses on changes that occur when atoms and molecules as reactants form product compounds with different chemical properties. Teachers may have students perform simple reactions or demonstrate the reactions for students. All students should be able to learn the more important chemical reactions and the elements involved in them, especially if common compounds such as vinegar (acetic acid), baking soda (sodium bicarbonate), table salt (sodium chloride), carbonated water, and nutritional minerals and foods are used in activities or demonstrations. An example might involve adding calcium chloride and baking soda to water. Such reactions demonstrate clearly the differences in properties between reactants (solids and liquid) and products (solid, liquid, and gas).

5. b. *Students know* the idea of atoms explains the conservation of matter: In chemical reactions the number of atoms stays the same no matter how they are arranged, so their total mass stays the same.

The conservation of matter is a classical concept, reinforcing the idea that atoms are the fundamental building blocks of matter. Atoms do not appear or disappear in traditional chemical reactions in which the constituent atoms and/or polyatomic ions are simply rearranged into new and different compounds. Conservation of atoms is fundamental to the idea of balancing chemical equations. The total number of atoms of each element in the reactants must equal the total number of atoms of each element in the products. The total number of atoms, hence the total mass, stays the same before and after the reaction.

There are several ways to teach and assess students' understanding of the concept of conservation of mass in chemical reactions. Weighing reactants before and products after a reaction shows that mass is neither gained nor lost. However, experimental errors are possible; the most common one is not sufficiently drying the products before weighing. One simple demonstration of the concept that atoms (or matter) are conserved in chemical reactions in which mass might appear to be lost is to determine the combined mass of a small, sealed container filled one-third with water, the screw-on cap, and one-quarter of an effervescent tablet. After the piece of tablet is dropped in the water, the container is immediately sealed. When the fizzing has stopped, the combined mass of the sealed container and the tablet should remain the same. After the seal is broken, much of the carbon dioxide gas formed by the reaction escapes, and the mass of the container and its contents decrease.

Students should also be taught to balance simple chemical equations. This step reinforces the idea that atoms do not appear or disappear in chemical reactions and, therefore, that matter is conserved.

5. c. *Students know* chemical reactions usually liberate heat or absorb heat.

In chemical reactions the atoms in the reactants rearrange to form products, and there is usually a net change in energy. Breaking bonds between atoms requires energy; making a bond releases energy. If the total making and breaking of all bonds for a particular chemical reaction results in a net release of energy, the reaction is said to be *exothermic.* The energy is typically released as heat into nearby matter. If the total making and breaking of bonds results in a net absorption of energy, the reaction is called *endothermic.* The energy is typically absorbed as heat from nearby matter, which therefore cools. A convenient way to demonstrate that chemical reactions release or absorb heat is the application of the hot packs or cold packs used for athletic injuries. The change in temperature produced by those packs may be the result of a chemical reaction, or it may be caused by a "heat of solution" and not by a chemical reaction. For example, dissolving is considered a physical and not a chemical change because the compound may be recovered, unchanged chemically, by evaporation.

5. d. *Students know* physical processes include freezing and boiling, in which a material changes form with no chemical reaction.

When heated, many solid materials undergo a reversible change of state into a liquid (melting). Under the standard condition of one atmosphere of pressure, the temperature at which such a solid material melts is the same as the temperature at which the liquid material freezes; this temperature, called the *melting point,* is characteristic of the material. Many liquid materials when heated also undergo a reversible change of state into a gas. Under one atmosphere of pressure, such a liquid material may boil; the temperature at which this occurs is also characteristic of the material and is called the *boiling point.* Such reversible changes—back and forth from solid to liquid or from liquid to gas—are called physical changes because no chemical change (a permanent reordering of the atoms into new molecules) occurs. Similarly, the dissolving of one substance into another, such as a solid or gas into a liquid, is often reversible (by evaporating the liquid to leave the solid or heating the liquid to drive out the gas) and is also called a physical rather than a chemical change. Physical changes can usually be undone to recover the original materials unchanged. Activities such as mixing iron filings with sand demonstrate a physical change. In this case a magnet can recover the iron filings from the mixture.

5. e. *Students know* how to determine whether a solution is acidic, basic, or neutral.

Indicators that change color are routinely used to determine whether a solution is acidic, basic, or neutral. A pH scale indicates with numbers the concentration of hydrogen ions in a solution and characterizes a solution as acidic (lower than 7), basic (higher than 7), or neutral (near 7). There are electrodes and electronic instruments that can measure directly the pH of a solution. Some acids and bases are defined other than by their hydrogen ion concentration, but they will be addressed in high school chemistry. Teachers may give students the opportunity to test solutions, including foods such as fruits and vegetables, with pH paper, litmus paper, indicator solutions, or pH meters to determine whether a solution or food is acidic, basic, or neutral. Students should be familiar with the pH scale to know what a given pH value indicates.

STANDARD SET 6. Chemistry of Living Systems (Life Sciences)

Because all living organisms are made up of atoms, chemical reactions take place continually in plants and animals, including humans. The uniqueness of organic chemistry stems from *chain polymers.* Life could not exist without the ability of some chemicals to join together, repetitively, to form large, complex molecules. Concepts learned in this standard set are critical for understanding fully the chemistry of the cells of organisms, genetics, ecology, and physiology that will be taught in the high school biology/life sciences standard sets.

6. Principles of chemistry underlie the functioning of biological systems. As a basis for understanding this concept:

a. *Students know* that carbon, because of its ability to combine in many ways with itself and other elements, has a central role in the chemistry of living organisms.

Carbon is unique among the elements because it can bond to itself and to many other elements. This attribute makes possible many different kinds of large, carbon-based molecules. Typically, carbon will make four separate covalent bonds (to other carbon atoms), but double and triple bonds are also possible. The variety of bonds allows carbon-based molecules to have a wide range of shapes and chemical properties. Key shapes include tetrahedral (e.g., methane and carbon tetrachloride), planar (e.g., formaldehyde and ethylene), and linear (e.g., acetylene and carbon dioxide). Students can research the nomenclature, composition, and structure of organic molecules by using textbooks and supplemental instructional materials. They can also construct models of carbon-based molecules by using commercial modeling kits or inexpensive alternatives (e.g., gumdrops and toothpicks).

6. b. *Students know* that living organisms are made of molecules consisting largely of carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur.

Living organisms are made up of a great variety of molecules consisting of many atoms (with carbon atoms playing the main roles), but the number of different elements involved is quite small. Carbon and only five other elements make up most of Earth's biomass. Those six elements, however, can combine in many different ways to make large, organic molecules and compounds. To demonstrate this idea, teachers may burn organic material, such as bone, leaves, wood, or a variety of candles. They may hold a cold glass or plate above the flame to condense droplets of water, one of the combustion products. They may also hold a heat-treated glass in the flames to collect carbon deposits in the form of soot. Students can discuss what elements were in the organic material. Teachers may draw students' attention to the black material that forms when meat is roasted or grilled or when toast is charred.

6. c. *Students know* that living organisms have many different kinds of molecules, including small ones, such as water and salt, and very large ones, such as carbohydrates, fats, proteins, and DNA.

Living organisms require a variety of molecules; some molecules contain carbon and some do not. The molecules that make up organisms and control the biochemical reactions that take place within them are usually large molecules, such as DNA, proteins, carbohydrates, and fats. Organisms also require simple substances, such as water and salt, to support their functioning. Teachers may encourage students to research why plants and animals need simple molecules such as water. Other activities for teachers may include squeezing the water from celery or turnips to demonstrate the presence of water. Or they may ask students how they can demonstrate that water is in fruits and vegetables (e.g., dried fruit). Teachers may also ask students how they know that there is salt in their bodies. Most students know that their perspiration tastes salty.

STANDARD SET 7. Periodic Table

Students will need to know the chemical symbols of the common elements. It will be helpful for them to be familiar with other properties of materials, such as melting temperatures, boiling points, density, hardness, and thermal and electrical conductivity. By the time students begin the study of this standard set, they should be familiar with the periodic table and should know the names and chemical symbols of most of the common elements. In this standard set they must now look in greater detail at and learn the significance of atomic numbers and isotopes and how they relate to the classification of elements. Students need to go more deeply into the elemental properties that serve as the basis for the periodic arrangement. Meeting the standards in this set will serve as a strong foundation for the study of atomic and molecular structures and of the relationship between these structures and the arrangement of elements on the periodic table that will take place in high school chemistry.

A common form of the periodic table has 18 columns (groups of elements) in the main body. This form shows the periodicity, or repeating pattern, of chemical and some physical properties of the elements. What varies most in published periodic tables is the information provided in the box that represents each element. The most useful tables are those that show the physical properties of the most common form of the element in addition to the atomic number and the atomic weight. A table that color-codes metals and nonmetals is also useful.

Elements shown toward the top of the periodic table are lighter, and those toward the bottom are heavier. Elements shown to the left are generally metallic, and those toward the right are nonmetallic. The word *metallic* refers to the collective properties of common metals: luster, malleability, high electrical and thermal (heat) conductivity. Although the majority of elements in the periodic table are metals, a few are classified as semimetals and may be found bordering the transition between the metals and nonmetals. When atoms from the left side of the table combine with atoms from the right side, they tend to form ionic salts, which are brittle crystalline compounds with high melting temperatures.

At the high school level, students will learn that the arrangement of the elements in the columns of the periodic table reflects the electron structure of the atoms of each element. This pattern explains the similarity in the chemical properties of the elements in each column of the periodic table.

Students should be readily able to use the periodic table to find the atomic number of an element and should know that there is a pattern of increasing atomic numbers as the table is read from left to right and down one row at a time. The lanthanides and actinides are placed off the table to save space; however, if they were placed in the table they would still be read in the same manner—from left to right and then down. Students should also know that the atomic number is the number of protons in the nucleus.

7. The organization of the periodic table is based on the properties of the elements and reflects the structure of atoms. As a basis for understanding this concept:

a. *Students know* how to identify regions corresponding to metals, nonmetals, and inert gases.

The periodic table of elements is structured so that metals are shown on the left, with the most reactive metals on the far left. Nonmetals are located on the right, with the most reactive next to the “inert” gases on the far right. Despite the name, inert gases are not truly inert. Although no naturally occurring inert gas compounds are known, some have been synthesized in the laboratory. Therefore most scientists use the term *noble* gas instead of inert gas. Semimetals, found between the metals and nonmetals in the periodic table, are elements, such as silicon, that have some properties of metals but also have properties that are typical of nonmetals. Although only a few elements fit this category, the unique electrical property of semimetal elements is that they are semiconductors, an essential property for computer chips. The rare earth elements can be used to produce very strong magnets.

Students should know that scientists have the right to name their discoveries and that some elements have been named after famous men and women scientists, such as curium, einsteinium, and seaborgium.

7. b. *Students know* each element has a specific number of protons in the nucleus (the atomic number) and each isotope of the element has a different but specific number of neutrons in the nucleus.

A rigorous definition of the term *element* is based on the number of protons in the atom's nucleus (the atomic number). All atoms of a given element have the same number of protons in the nucleus. Atoms with different atomic numbers are atoms of different elements. Although the number of protons is fixed for a particular element, the same is not true for the number of neutrons in the nucleus. An element that has different numbers of neutrons in its atoms is called an *isotope* of the element. For example, all hydrogen atoms have one proton in the nucleus, but there are two additional isotopes of hydrogen with different numbers of neutrons. One is called deuterium (one proton and one neutron), and the other is called tritium (one proton and two neutrons). The common isotope of hydrogen has one proton and no neutrons in its nucleus.

Some isotopes are *radioactive,* meaning that the nucleus is unstable and can spontaneously emit particles or trap an electron to become the nucleus of a different element with a different atomic number. All the isotopes of some elements are radioactive, such as element 43, technetium, or element 86, radon. No stable samples of those elements exist. Element 92, uranium, is another example of an element in which no stable isotopes exist. However, uranium (atomic weight 238) is found in nature because it decays so slowly that it is still present in Earth's crust. The atomic number of each element represents the number of protons in the nucleus. Therefore, as the atomic number increases, the mass of the atoms of succeeding elements generally increases although exceptions exist because of the varying numbers of neutrons in some isotopes. Typically, however, the atoms of the elements in the periodic table increase from left to right, and those elements listed in the lower rows are more massive than those in the upper rows.

7. c. *Students know* substances can be classified by their properties, including their melting temperature, density, hardness, and thermal and electrical conductivity.

The physical properties of substances reflect their chemical composition and atomic structure. The melting temperature or hardness of the common forms of the elements is related to the forces that hold the atoms and molecules together. One can compare the boiling points of carbon and nitrogen. Carbon is solid up to very high temperatures (3,600 degrees Celsius); nitrogen, the element next to it, is a gas until it is cooled to below negative 196 degrees Celsius. This dramatic difference between two adjacent elements on the periodic table shows there must be very different intermolecular forces acting as a result of a slight change in atomic structure.

Density is the mass per unit volume and is a function of both the masses of individual atoms and the closeness with which the atoms are packed.

Electrical conductivity and thermal conductivity are strongly dependent on how tightly electrons are held to individual atoms. Metals and nonmetals may be found in portions of the periodic table. Metal atoms combine in regular patterns in which some electrons are free to move from atom to atom, a condition that accounts for both high electrical and high thermal conductivity.

STANDARD SET 8. Density and Buoyancy

The central goal of this standard set is to be able to answer the simple question, Will an object sink or will it float? Students will learn that density is a physical property of a substance independent of how much of the substance is available, and they will be able to relate the property of density to the phenomenon of buoyancy. Archimedes, a Greek mathematician, is credited with first recognizing that different substances have different densities and that fluids exert a buoyant force on objects submerged in them. He came to this understanding while trying to determine what else was in a supposedly gold crown.

Archimedes came to a simple realization: water does not sink in water. That is, if one focuses on one drop of water in a container of water (and if one could keep the drop intact and distinct), the drop would not fall to the bottom of the container even though it has weight. The surrounding water must exert an upward buoyant force on the drop equal to the weight of the drop. The drop would fall if its weight were greater than the buoyant force supplied by the surrounding water. The drop would rise if it weighed less than the buoyant force. The surrounding water exerts an upward buoyant force on any volume within it equal to the weight of that volume of water. Understanding the nature of floating and sinking led Archimedes to realize that different substances have different densities—the key to determining whether the crown was gold or a fake.

Density is a property characteristic of the material itself and does not change whether the material is subdivided or the amount available is altered. Different substances have different densities, so knowing the density of a sample is useful in determining its composition. For example, the composition of Earth's interior was first inferred to be different from the composition of rocks in the lithosphere because the density of lithospheric rocks is different from the average density of Earth.

The density of solids and liquids, the two condensed states of matter, does not vary much with changes in pressure or temperature. However, small differences in density within a liquid or gas may be caused by local heating and result in convection currents. Because gases are so compressible, their densities may vary over a wide range of values. That is why tables of measured values of density are found only for solids and liquids.

Most fluids (gases and liquids) are very poor conductors of heat. Normally, fluids expand when their temperature increases because of the more rapid motion of the constituent molecules. If a fluid is heated locally, the thermal energy is not conducted rapidly to other parts of the fluid; the region that is hotter expands, becoming less dense than the cooler surrounding fluid. The buoyant force supplied by the cooler surrounding fluid on the hotter expanded region is greater than the weight of the hotter region. This force causes the hotter, less dense region of fluid to be pushed up, a phenomenon known as "Hot air rises."

A thorough understanding of density and buoyancy will be helpful in mastering the earth science standards in high school.

8. All objects experience a buoyant force when immersed in a fluid. As a basis for understanding this concept:

a. *Students know* density is mass per unit volume.

Density is a physical property of a substance independent of the quantity of the substance. That is, a cubic centimeter of a substance has the same density as a cubic kilometer. Density may be expressed in terms of any combination of measurements of mass and volume. The measurement units most commonly used in science are grams per cubic centimeter for solids and grams per milliliter for liquids.

8. b. *Students know* how to calculate the density of substances (regular and irregular solids and liquids) from measurements of mass and volume.

Density is calculated by dividing the mass of some quantity of material by its volume. Mass may be determined by placing the material on a balance or scale and subtracting the mass of its container. The volume of a liquid may be measured easily by using graduated cylinders, and the volume of a regular solid may be measured by using a ruler and the appropriate geometry formula. It is not as simple, however, to measure the volume of an irregular solid. The volume of an irregularly shaped solid object may be determined by water displacement.

8. c. *Students know* the buoyant force on an object in a fluid is an upward force equal to the weight of the fluid the object has displaced.

Whether an object will float depends on the magnitude of the buoyant force of the surrounding fluid (liquid or gas) compared with the weight of the object. The buoyant force is equal to the weight of the volume of fluid displaced by the object. The net force acting on a submerged body is the difference between the upward buoyant force of the surrounding fluid and the downward pull of gravity on the object (its weight). The same relationship applies to two separate fluids of differing densities. Therefore, if the volume of the fluid displaced by a submerged solid object weighs more than the object, the object will rise to the surface and float. If the values are the same, the object is said to be neutrally buoyant and will neither sink nor rise to the surface. If the volume of the surrounding fluid displaced by a solid object weighs less than the object, the object will sink.

The buoyant force can be demonstrated convincingly by placing a water-filled, sealed plastic sandwich bag in a container of water and noting that the sandwich bag filled with water does not sink even though gravity applies a downward force on the water-filled bag (its weight). Therefore, there must be an upward, buoyant force applied by the surrounding water. If the sandwich bag is filled with a liquid that weighs more than an equal volume of water, it will sink. If the liquid in the sandwich bag is less dense than water, it will float. Students can fill another sandwich bag with hot water to demonstrate that it floats in room-temperature water. They can fill a third sandwich bag with water slightly above the freezing point and repeat the experiment to show that cold water will sink in room-temperature water.

To demonstrate buoyant forces dramatically, the teacher may place a heavy object, such as a large rock, in a large container of water and ask students first to lift the object in the container without removing the object from the water. Then the teacher asks students to lift the object completely from the water. Students are usually startled by how much easier it is to lift the object while it is in a container of water than to lift that same object when it is on a dry surface. People can move heavy stones from one place to another when the stones are immersed in rivers and lakes, but they often cannot lift the stone from the water. A small beach ball pushed down into a large container of water produces the same effect in reverse for students who have never experienced the large buoyant force that water can exert on a volume that is mostly air.

8. d. *Students know* how to predict whether an object will float or sink.

The most direct way to predict whether a substance or solid object will sink or float in a fluid is to compare the density of the substance or object with the density of the fluid, either by measurement or by looking up the values on a table of densities. If the object is less dense than the fluid, it will float. Materials with densities greater than that of a liquid can be made to float on the liquid (e.g., steel boats and concrete canoes floating on water) if they can be shaped to displace a volume of the liquid equal to their weight before they submerge completely.

The density of liquids may be determined by using a hydrometer, either one that is commercially available or one that is made from a pencil with a thumbtack in the eraser. The depth to which an object of uniform density will sink in a liquid is a relative measure of the density of the liquid. Simple hydrometers, based on this principle, can be used to compare the densities of a variety of liquids with the density of water. The length of the hydrometer submerged in an unknown liquid *(U)* compared with the length submerged in water *(W)* can be used to determine the density of an unknown liquid *(W/U)* in metric units of grams per cubic centimeter. How far a pencil hydrometer sinks in water may be marked as “1 gram per cubic centimeter.” If the pencil sinks twice as far in another liquid, its density is 0.5 gram per cubic centimeter; if it sinks half as far, the density is 2 grams per cubic centimeter; and so on.

Air is also a fluid and exerts a buoyant force on objects submerged in it. Hot-air balloons rise because the upward buoyant force of the cooler surrounding air is greater than the weight of the hot, less dense air inside the balloon and the trappings of the balloon. Helium balloons rise because a volume of helium gas is much lighter than an equal volume of air at the same temperature and pressure.

STANDARD SET 9. Investigation and Experimentation

Experiments can yield consistent, reproducible answers, but the answers may be incorrect or off the mark for many reasons. By the time students complete grade eight, they should have a foundation in experimental design and be able to apply logical thinking processes to evaluate experimental results and conclusions. Mathematical representation of data is the key to making quantitative scientific predictions. Graphs expressing linear relationships utilize proportional reasoning and algebra. Students should be taught to apply their knowledge of proportions and algebra to the reporting and analysis of data from experiments.

9. Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content in the other three strands, students should develop their own questions and perform investigations. Students will:

a. Plan and conduct a scientific investigation to test a hypothesis.

b. Evaluate the accuracy and reproducibility of data.

c. Distinguish between variable and controlled parameters in a test.

d. Recognize the slope of the linear graph as the constant in the relationship $y = kx$ and apply this principle in interpreting graphs constructed from data.

e. Construct appropriate graphs from data and develop quantitative statements about the relationships between variables.

f. Apply simple mathematical relationships to determine a missing quantity in a mathematic expression, given the two remaining terms (including speed = distance/time, density = mass/volume, force = pressure × area, volume = area × height).

g. Distinguish between linear and nonlinear relationships on a graph of data.

Notes

1. *Reading/Language Arts Framework for California Public Schools, Kindergarten Through Grade Twelve.* Sacramento: California Department of Education, 1999; *Mathematics Framework for California Public Schools, Kindergarten Through Grade Twelve* (Revised edition). Sacramento: California Department of Education, 2000.
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5. Charles Darwin, *On the Origin of Species by Means of Natural Selection.* Reprinted from the 6th edition. New York: Macmillan, 1927.
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The Science Content Standards for Grades Nine Through Twelve

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The science content standards for kindergarten through grade eight provide the background for students to succeed with the science content standards for grades nine through twelve. Aligning the high school curriculum to offer standards-based courses for every student will put new demands on schools and science departments. However, the reward for successfully meeting the challenge will be that high school graduates can attain the highest level of science literacy achieved by students in more than two decades.

Changing to a program based on the science content standards will require a restructuring of the high school curriculum, although the science that was generally taught in California before the *Science Content Standards for California Public Schools* was published is mostly included in the standards.[1] The successful implementation of standards-based kindergarten through grade eight programs aligned to this *Science Framework* should enable more students to take standards-based courses in high school. This chapter provides guidance for teaching students who have mastered the kindergarten through grade eight materials. To achieve this mastery will require many years of effort, and school districts should adjust their programs appropriately as their students have the opportunity to learn the prerequisite material in the earlier grades.

School districts are responsible for their curriculum and must decide how to structure their courses to teach the science standards. Traditionally, biology has been taught in the tenth grade, followed by chemistry and then possibly by physics. However, this sequence dates from a time when the content of the biology course was descriptive and that of the physics course was the most quantitative among the science disciplines. The high school science standards allow for other structures. Because districts need flexibility to design their own course structure, this chapter is presented in modular format—no sequence or emphasis is prescribed.

Appropriate to the rigor of the standards, each section covers a particular scientific discipline: physics, chemistry, biology/life sciences, and earth sciences. Along with meeting the subject-matter requirements for science, every student should learn the content in the full set of Investigation and Experimentation standards and have an opportunity to learn the slightly more advanced material in the standards that are marked with an asterisk.

In 1997 California established the Digital High School program, ensuring that all high schools throughout the state would have access to technology to improve student achievement in science and other academic subjects. Many schools purchased materials for scientific-based technology, and their use should be integrated into science programs. Technology can be used to teach some science standards and to assess students' understanding. Science education provides an opportunity to instruct students in gathering, graphing, tracking, and interpreting data through the use of technological tools, such as word processing, spreadsheets, and database development. Related concepts from science, mathematics, and language arts can be merged in the development of a science experiment and its subsequent analysis.

Safety is always the foremost consideration in the design of demonstrations, laboratories, and science experiments. The importance of safety is evident because scientists and engineers in universities and industries are required to follow strict health and safety regulations. Safety needs to be taught. Teachers should be familiar with the *Science Safety Handbook for California Public Schools*.[2] It contains specific, useful information relevant to classroom science teachers. School administrators, teachers, parents/guardians, and students have a legal and moral obligation to promote safety in science education. Knowing and following safe practices in science are a part of understanding the nature of science and scientific enterprise.

Physics

Many scientists and engineers consider physics the most basic of all sciences. It covers the study of motion, forces, energy, heat, waves, light, electricity, and magnetism. Physics focuses on the development of models deeply rooted in scientific inquiry, in which mathematics is used to describe and predict natural phenomena and to express principles and theories. Understanding physics requires the ability to use algebra, geometry, and trigonometry. This need for mathematics has kept all but a very few students in this country from studying physics. Other countries, however, have met this challenge by introducing the concepts of physics to students during a period of several years, starting in the earlier grade levels. Topics requiring little or no mathematics are introduced first, and students progress to more sophisticated and quantitative treatments as they learn more mathematics. The California standards emulate this successful approach.

All students can learn high school physics. Many will have enough foundational skills and knowledge of mathematics from their science curriculum in kindergarten through grade eight to study motion, forces, heat, and light. In high school, students should develop a working knowledge of algebra, geometry, and simple trigonometry to understand and gain access to the power of physics. Some will need to learn or relearn algebra, geometry, and trigonometry skills while studying physics. The need for such mathematics review should lessen over time as California's rigorous mathematics standards are implemented. Students who intend to pursue careers in science or engineering will need to master the physics content called for in the California standards, including the standards marked with an asterisk. (Note that equations appearing in this section are numbered consecutively.)

STANDARD SET 1. Motion and Forces

Motion deals with the changes of an object's position over time. Inherent in any useful study of motion is the concept of force, which represents the existence of physical interactions. Although Newton's laws provide a good platform from which to analyze forces, those laws do not address the origin of forces. Fundamental forces in nature govern the physical behavior of the universe. One of these fundamental forces, gravity, influences objects with mass but acts at a distance, or without any direct contact between the objects. The electromagnetic force is also a fundamental force that operates across a distance. These standards on motion and forces provide the foundation for understanding some key similarities—and differences—between these two forces. A working knowledge of basic algebra and geometry is an essential prerequisite for studying these concepts.

In standard sets presented earlier at lower grade levels, students were introduced to the idea that the motion of objects can be observed and measured, and they learned that a force can change the motion of an object by giving it a push or a pull. The topic of "Motion and Forces" at the high school level builds directly on the eighth grade Standard Set 1, "Motion," and Standard Set 2, "Forces," both of which introduce the notions of balanced forces and of net force (see Chapter 4). Students should know the difference between speed and velocity and should be able to interpret graphs for linear motion that plot relationships between two variables, such as speed versus time. Students should also understand the vector nature of forces. The concepts of gravity and of inertia as a resistance to a change in motion should have been introduced in the eighth grade.

1. Newton's laws predict the motion of most objects. As a basis for understanding this concept:

a. *Students know* how to solve problems that involve constant speed and average speed.

The rate at which an object moves is called its *speed.* Speed is measured in distance per unit time (e.g., meters/second). Velocity **v** is a vector quantity and therefore has both a magnitude—the speed—and a direction. If an object travels at a constant speed, a simple linear relationship exists between the speed, or rate of motion r; distance traveled d; and time t, as shown in

$$d = rt. \qquad \text{(eq. 1)}$$

If speed does not remain constant but varies with time, *average speed* can be defined as the total distance traveled divided by the total time required for the trip.

1. b. *Students know* that when forces are balanced, no acceleration occurs; thus an object continues to move at a constant speed or stays at rest (Newton's first law).

If an object's velocity v changes with time t, then the object is said to accelerate. For motion in one dimension, the definition of acceleration a is

$$a = \Delta v/\Delta t\,, \qquad \text{(eq. 2)}$$

where the Greek capital letter delta (Δ) stands for "a change of." *Acceleration* is defined as change in velocity per unit time. (Another way to state this definition is that *acceleration* is a change in distance per unit time per unit time, producing acceleration units of, for example, m/s^2 [meters per second squared or meters per second per second].) Acceleration is a vector quantity and therefore has both magnitude and direction. A push or a pull (force) needs to be applied to make an object accelerate. Force is another vector quantity.

A vector quantity, such as force, can be resolved into its x, y, and z components, F_x, F_y, and F_z. More than one force can be applied to an object simultaneously. If the forces point in the same direction, their magnitudes add; if the forces point in opposite directions, their magnitudes subtract. The net (overall) force can be calculated by adding forces along a line algebraically and keeping track of the direction and signs. If an object is subject to only one force, or to multiple forces whose vector sum is not zero, there must be a net force on the object. However, if there is no net force on an object already in motion, that object continues to move at a constant velocity. An object at rest remains at rest if no net force is applied to it. This principle is Newton's first law of motion.

1. c. *Students know* how to apply the law $F = ma$ to solve one-dimensional motion problems that involve constant forces (Newton's second law).

If a net force is applied to an object, the object will accelerate. The relationship between the net force F applied to an object, the object's mass m, and the resulting acceleration a is given by Newton's second law of motion

$$F = ma \,. \qquad \text{(eq. 3)}$$

If mass is in kilograms (kg) and acceleration is in meters per second squared (m/s^2), then force is measured in Newtons, with 1 Newton = 1 kilogram-meter per second squared (1 $kg\text{-}m/s^2$).

If the net force on an object is constant, then the object will undergo constant acceleration. When studying constant force, students should be able to make use of the following equations to describe the motion of an object in one dimension at any elapsed time t by calculating its velocity v and distance from the origin d:

$$v = v_0 + at \,, \qquad \text{(eq. 4)}$$

$$d = d_0 + v_0 t + \tfrac{1}{2} at^2 \,. \qquad \text{(eq. 5)}$$

In these equations m is the mass, v_0 is the initial velocity, d_0 is the initial position (distance from origin) of the object, and t is the time during which the force F is applied.

1. d. *Students know* that when one object exerts a force on a second object, the second object always exerts a force of equal magnitude and in the opposite direction (Newton's third law).

Newton's third law of motion is more commonly stated as, "To every action there is always an equal and opposite reaction." The mutual reactions of two bodies are always equal and point in opposite directions. Mathematically stated, if object 1 pushes on object 2 with a force $\mathbf{F}_{12}$, then object 2 pushes on object 1 with a force $\mathbf{F}_{21}$ such that

$$\mathbf{F}_{21} = -\mathbf{F}_{12} \,. \qquad \text{(eq. 6)}$$

This universal law applies, for example, to every object on the surface of Earth. Trees, rocks, buildings, and cars, even the atmosphere, are all subject to the downward force of gravity. In all cases Earth exerts an equal and opposite upward push on the objects. Stars exist because of the balance between the inward force of gravity and the outward pressure of their hot interior gases.

1. e. *Students know* the relationship between the universal law of gravitation and the effect of gravity on an object at the surface of Earth. (See Standard 1.m.*)

Since the time of Galileo's reputed experiment of dropping objects from the tower of Pisa, it has been understood that in the absence of air resistance, all objects near Earth's surface, regardless of their mass or composition, accelerate downward toward Earth's center at 9.8 m/s^2. Through Newton's second law, this principle can be expressed as

$$F = w = mg \text{ (where } g \approx 9.8\text{m/s}^2 \text{ is the acceleration due to gravity).} \qquad \text{(eq. 7)}$$

The gravitational force pulling on an object is called the object's weight w and is measured in Newtons.

1. f. *Students know* applying a force to an object perpendicular to the direction of its motion causes the object to change direction but not speed (e.g., Earth's gravitational force causes a satellite in a circular orbit to change direction but not speed).

A force that acts on an object may act in any direction. The component of the force parallel to the direction of motion changes the speed of the object, and the components perpendicular to the motion change the direction in which the object travels.

1. g. *Students know* circular motion requires the application of a constant force directed toward the center of the circle.

An object moving with constant speed in a circle is in uniform circular motion. The direction of motion continuously changes because of a force that always points inward toward the center of the circle. Such a centrally directed force is called a *centripetal force.* If the mass of the object is m, its speed is v, and the radius of the circle in which the object travels is r, then the magnitude of the force causing the circular motion is

$$F_c = mv^2/r\,. \qquad \text{(eq. 8)}$$

Examples of centripetal forces are the tension in a string attached to a ball that is swung in a circle, the pull of gravity on a satellite in orbit around Earth, the electrical forces that deflect electrons in a television tube, and the magnetic forces that turn a charged particle.

1. h.* *Students know* Newton's laws are not exact but provide very good approximations unless an object is moving close to the speed of light or is small enough that quantum effects are important.

Newton's laws are not exact but are excellent approximations valid in domains involving low speeds and macroscopic objects. However, when the speed of an object approaches the speed of light (3×10^8 m/s), Einstein's theory of special relativity is required to describe the motion of the object accurately. Among the major differences between Einstein's and Newton's theories of mechanics are that (1) the maximum attainable speed of an object is the speed of light; (2) a moving clock runs more slowly than does a stationary one; (3) the length of an object depends on its velocity with respect to the observer; and (4) the apparent mass of an object increases as its speed increases.

The other domain in which Newtonian mechanics breaks down is that of very small objects, such as atoms or atomic nuclei. Here the wavelike nature of matter becomes important, and quantum mechanics better describes the submicroscopic world. Newtonian mechanics assumes that if the motion of a particle is measured with great accuracy and all the masses and forces that are involved are also known, it is always possible to predict with equally great accuracy the future state of motion of the particle. Quantum mechanics shows that such certainty is not always possible. Sometimes only the probability of an outcome can be predicted.

1. i.* *Students know* how to solve two-dimensional trajectory problems.

Students can consider the problem of a ball of mass m thrown upward into the air at some angle. The motion of the ball will have horizontal and vertical components that are independent of one another. If air resistance is ignored, there will be no horizontal force acting against the ball to slow it down. While the ball is in flight then, only a single vertical force, gravity, is acting on the ball (e.g., $F = w = mg$ downward). If students know the angle and the height from which the ball is thrown and the ball's initial velocity, they will be able to predict the path of the ball and to calculate how high the ball will go, how far it will travel before it strikes the ground, and how long it will be in the air.

1. j.* *Students know* how to resolve two-dimensional vectors into their components and calculate the magnitude and direction of a vector from its components.

In a two-dimensional system, two quantities are needed to describe a vector. A vector $\mathbf{r}$ can be completely specified by a magnitude r and an angle Φ or by its x and y components (i.e., r_x and r_y). Simple trigonometry can be applied to resolve a vector into its components (e.g., $r_x = r \cos \Phi$ and $r_y = r \sin \Phi$) and to calculate the magnitude and direction of a vector from its components ($r^2 = r_x^2 + r_y^2$ and $\tan \Phi = r_y/r_x$).

1. k.* *Students know* how to solve two-dimensional problems involving balanced forces (statics).

A body at rest that is subject to no net force is in static equilibrium. Examples of static equilibrium are a book resting on the surface of a table and a ladder leaning at rest against a wall. Because the book and table remain at rest does not imply that no forces act on these objects but does imply that the vector sum of all these forces is zero. In particular, the components of the forces in any particular direction sum to zero. Thus for an object that remains at rest,

$$\sum F_y = 0, \qquad \text{(eq. 9)}$$

where the Greek capital letter sigma (Σ) means to "sum over or add" and F_y represents the components in any chosen direction y of the forces acting on the object. One sample problem appears in Figure 2, "Calculation of Force." Students are given the weight of a hanging object, the lengths of the ropes holding it in place, and the distance between the anchors. The students are asked to calculate the forces, called *tension,* along ropes of equal length. Students find this problem difficult because the vector force diagram they should use to solve the problem is often confused with the physical lengths of the ropes.

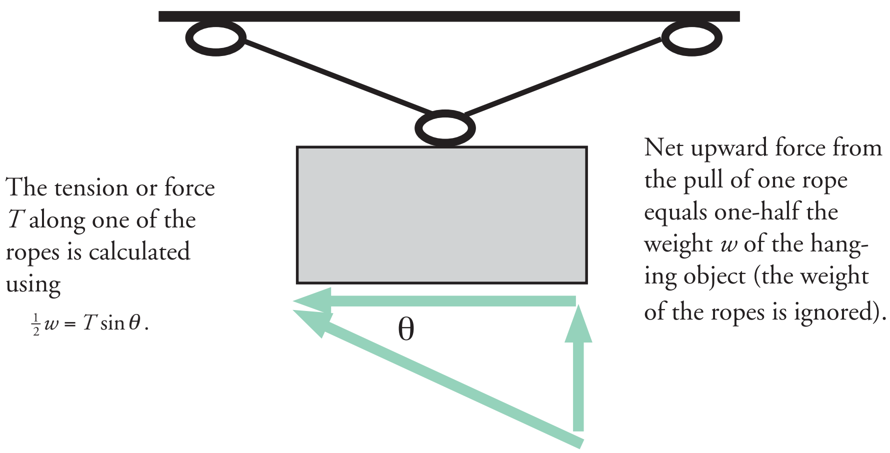

Fig. 2. Calculation of Force

1. l.* *Students know* how to solve problems in circular motion by using the formula for centripetal acceleration in the following form: $a = v^2/r$.

The speed of an object undergoing uniform circular motion does not vary, but the object's direction does and hence the object's velocity. Thus the object is constantly accelerating. The magnitude of this centripetal acceleration is

$$a_c = F_c/m = v^2/r\,, \qquad \text{(eq. 10)}$$

and the direction of the centripetal acceleration vector rotates so that it always points inward toward the center of the circle.

1. m.* *Students know* how to solve problems involving the forces between two electric charges at a distance (Coulomb's law) or the forces between two masses at a distance (universal gravitation).

Standard Set 5 for physics, "Electric and Magnetic Phenomena," which appears later in this section, shows that the origin of the force between two masses and between two electric charges is entirely different. However, the forces involved, the gravitational and the electromagnetic forces, are both inverse square relationships. Coulomb's law (in a vacuum) is written

$$F_q = kq_1q_2/r^2 \text{ ,} \qquad \text{(eq. 11)}$$

where $k = 9 \times 10^9$ Nm^2/coul^2, q_1 and q_2 are charges (positive [+] or negative [−]), r is the distance separating the charges, and F_q is the force resulting from the two charges. The force is repulsive if the charges are the same sign and attractive if they are different.

Newton's law of universal gravitation states that if two objects have masses m_1 and m_2, with centers of mass separated from each other by a distance r, then each object exerts an attractive force on the other; the magnitude of this force is

$$F_g = Gm_1m_2/r^2 \text{ ,} \qquad \text{(eq. 12)}$$

where G is the universal gravitational constant, equal to 6.67×10^{-11} newton-m^2/kg^2. For the case of a small object falling freely near the surface of Earth, students should understand that

$$g = Gm_e/r_e^2 = 9.8 \text{ m/s}^2 \text{ ,} \qquad \text{(eq. 13)}$$

where m_e and r_e are the mass and radius of Earth. Students might be interested to know that Henry Cavendish's measurement of G, completed around the year 1800, was the last piece of information needed to calculate the mass of Earth.

STANDARD SET 2. Conservation of Energy and Momentum

The concept of energy was introduced and discussed several times in the lower grades, from the physical sciences through the life sciences. In fact, every process involves some transfer of energy. In Standard Set 2 *energy* is classified as *kinetic,* meaning related to an object's motion, or as *potential,* meaning related to an object's stored energy. The energy of a closed system is conserved. Another useful conservation law, conservation of momentum, is introduced and is shown to be a direct consequence of Newton's laws. The power and importance of these conservation laws are that they allow physicists to predict the motion of objects without having to know the details of the dynamics and interactions in a given system.

Through the standard sets introduced in the lower grade levels, students should have learned about forces and motion and the idea of energy. They should have been taught the role of energy in living organisms and the effects of energy on Earth's weather. The standards presented earlier also call for student exposure to energy conservation, a concept that is essential to the topics contained in the high school physics standard sets 3, 4, and 5 and in several standard sets in chemistry and earth sciences.

2. The laws of conservation of energy and momentum provide a way to predict and describe the movement of objects. As a basis for understanding this concept:

a. *Students know* how to calculate kinetic energy by using the formula $E = \frac{1}{2}mv^2$.

Kinetic energy is energy of motion. The kinetic energy of an object equals the work that was needed to create the observed motion. This work can be related to the net force applied to the object along the line of the motion. The work done on an object by a force is equal to the component of the force along the direction of motion multiplied by the distance the object moved:

$$W = Fd \,. \qquad \text{(eq. 14)}$$

The work needed to accelerate an object of mass m from rest to a speed v is $\frac{1}{2}mv^2$. This quantity is defined as the kinetic energy E. The units of energy are joules, in which 1 joule = 1 kilogram-meter squared per second squared (1 kg-m^2/s^2) = 1 newton-meter. Energy is a *scalar* quantity, meaning that energy has a magnitude but no direction.

2. b. *Students know* how to calculate changes in gravitational potential energy near Earth by using the formula (change in potential energy) = *mgh* (*h* is the change in the elevation).

Students can combine equations (3) and (14) to find the work done in lifting an object of weight mg through a vertical distance h, as shown in

$$W = mgh \,. \qquad \text{(eq. 15)}$$

Work and energy have the same units. Therefore, one can define mgh as the change in gravitational potential energy associated with the change in elevation h of the mass m.

2. c. *Students know* how to solve problems involving conservation of energy in simple systems, such as falling objects.

Equations (4) and (5) can be used to show that if the object dealt with in Standard 2.b is released from rest and allowed to fall freely, it will strike the ground with a speed

$$v = \sqrt{2gh}\,, \qquad \text{(eq. 16)}$$

and its kinetic energy at the instant of impact will be

$$E = \tfrac{1}{2}mv^2 = \tfrac{1}{2}m(2gh) = mgh \,. \qquad \text{(eq. 17)}$$

The total energy T of the object is then defined as the sum of kinetic plus potential energy

$$T = E + PE \,. \qquad \text{(eq. 18)}$$

This sum is conserved in a closed system for such forces as gravity and electromagnetic interactions and those produced by ideal springs. Thus,

$$\Delta E + \Delta PE = 0 \,. \qquad \text{(eq. 19)}$$

Therefore, the change in kinetic energy equals the negative of the change in potential energy. This principle is a consequence of the law of the conservation of energy. Energy can be converted from one form to another, but in a closed system the total energy remains the same.

2. d. *Students know* how to calculate momentum as the product *mv.*

The momentum **p** of an object is defined as the product of its mass m and its velocity **v.** Momentum is thus a vector quantity, having both a magnitude and a direction. The units of momentum are kg-m/s. The magnitude of the momentum is mv, the product of the object's mass and its speed.

2. e. *Students know* momentum is a separately conserved quantity different from energy.

If no net force is acting on an object or on a system of objects, the momentum remains constant. That is, neither its magnitude nor its direction changes with time. Conservation of momentum is another fundamental law of physics.

2. f. *Students know* an unbalanced force on an object produces a change in its momentum.

As discussed in the section for Standard 1.c, if the net force on an object is not zero, then its velocity and hence its momentum will change. Motion resulting from a constant force **F** acting on an object for a time Δt causes a change in momentum of $\mathbf{F}\Delta t$. This change in momentum is called an *impulse.* (Note that the units of impulse are the same as those of momentum [i.e., newton-second = kg-m/s].) Depending on the direction of the force, the impulse can increase, decrease, or change the direction of the momentum of an object.

2. g. *Students know* how to solve problems involving elastic and inelastic collisions in one dimension by using the principles of conservation of momentum and energy.

Momentum is always conserved in collisions. Collisions that also conserve kinetic energy are called *elastic collisions;* that is, the kinetic energy before and after the collision is the same. Billiard balls colliding on smooth pool tables and gliders colliding on frictionless air tracks are approximate examples. Collisions in which kinetic energy is not conserved are called *inelastic collisions.* An example is a golf ball colliding with a ball of putty and the two balls sticking together. Some of the kinetic energy in inelastic collisions is transformed into other types of energy, such as thermal or potential energy. In all cases the total energy of the system is conserved.

2. h.* *Students know* how to solve problems involving conservation of energy in simple systems with various sources of potential energy, such as capacitors and springs.

An ideal spring is an example of a conservative system. The force required either to stretch or to compress a spring by a displacement x from its equilibrium (unstretched) length is

$$F = kx\,, \qquad \text{(eq. 20)}$$

where k is the spring constant that measures a spring's stiffness. A graph of the magnitude of this force as a function of the compression shows that the force varies linearly from zero to kx as the spring is compressed. The area under this graph is the work done in compressing the spring and is equal to

$$\tfrac{1}{2}(\text{base})(\text{height}) = \tfrac{1}{2}kx^2\,. \qquad \text{(eq. 21)}$$

This is also the potential energy stored in the spring.

A capacitor stores charge. The charge Q that is stored depends on the voltage V according to

$$Q = CV\,, \qquad \text{(eq. 22)}$$

where the constant C is called the *capacitance.* (Notice that this equation and the equation for a spring [eq. 20] have the same form.) The energy stored in a capacitor is given by the equation

$$E = \tfrac{1}{2}CV^2, \qquad \text{(eq. 23)}$$

which also has the same form as the equation that gives the energy stored by a spring.

STANDARD SET 3. Heat and Thermodynamics

The concept of heat (thermal energy) is related to all scientific disciplines. Energy transfer, molecular motion, temperature, pressure, and thermal conductivity are integral parts of physics, chemistry, biology, and earth science. Thermodynamics deals with exchanges of energy between systems.

If students in high school have not yet covered the chemistry standards, the related topics from those standards should be introduced. (See the following standards for chemistry in this chapter: 4.a through 4.h, "Gases and Their Properties," and 7.a through 7.d, "Chemical Thermodynamics." Specific chemistry topics that are useful or necessary for promoting a more complete understanding of Standard

Set 3 are specifically mentioned, when relevant, under the sections with detailed descriptions.

At the atomic and molecular levels, all matter is continuously in motion. For example, individual molecules of nitrogen, oxygen, and other gases that make up the air inside a balloon move at varying speeds in random directions, vibrating and rotating. The collisions of these molecules with the inner surface of the balloon create the pressure that supports the balloon against atmospheric pressure.

Considerable confusion exists in scientific literature about the definitions of the terms *heat* and *thermal energy.* Some texts define *heat* strictly as "transfer of energy." These science content standards use the term *heat* interchangeably with *thermal energy.* However, it is less confusing to reserve the term *heat* for thermodynamic situations in which energy is transferred either because of differences in temperature or through work done by or on a system. In this sense both *heat* and *work* have meaning only as they describe energy exchanges into and out of the system, adding or subtracting from a system's store of internal energy.

Students, just like scientists of the eighteenth century, might easily fall prey to the misconception that heat is a substance. Students should be cautioned that heat is energy, not a material substance, and that *heat flow* refers not to material flow but to the transfer of energy from one place to another. Confusion is most apt to arise when dealing with heat transfer by convection; that is, when heat is transferred through actual motion of hot and cold material along a thermal gradient. Heating a material such as air causes it to expand and leads to differences in density that drive the movement of heated material.

Students also often confuse temperature and heat. From a molecular viewpoint, *temperature* is a measure of the average translational kinetic energy of a molecule, as shown in equation (27). (See also Standard Set 7 in the chemistry section in this chapter.) Studies of the temperature of materials as they pass through phase transitions may also help students understand the differences and relationships between heat and temperature.

A way to avoid confusion is to reserve the use of the word *heat* for situations in which heat transfer is involved, as described in the next section.

3. Energy cannot be created or destroyed, although in many processes energy is transferred to the environment as heat. As a basis for understanding this concept:

a. *Students know* heat flow and work are two forms of energy transfer between systems.

Heat transfer is energy flow from one system to another because of differences in temperature or because of mechanical work. The energy that flows into a pot of cold water put on a hot stove is an example of heat transfer. This energy increases the kinetic energy of the random motion of the molecules of water and therefore the temperature of the water rises. When the water reaches 100°C, a new phenomenon, a phase transition, occurs: the water vaporizes, or boils. Although energy continues to flow into the water, the kinetic energy of the water molecules does not increase; therefore the temperature of the water remains constant. As the water changes from a liquid to a gas, the energy goes instead into breaking the bonds that hold one molecule of liquid water to another. The energy required (per unit mass or mole of liquid) to change a particular liquid at its boiling temperature into a gas is called the liquid's *latent heat of vaporization.*

Mechanical work can change temperature too (e.g., when the forces of friction heat objects or when a gas is compressed and so warms). Conversely, changes in temperature can do mechanical work (e.g., warming a container of gas that is sealed by a piston will cause the gas to expand and the piston to move).

Heat is energy that moves between a system and its environment because of a temperature difference between them. Every system has its internal energy, that is, the energy required to assemble the system; and this energy is independent of any particular path or means by which the system is assembled. The transfer of internal energy from one system to another, because of a temperature difference, is known as *heat flow.* There are three basic kinds of heat flow: conduction, convection, and radiation. Students should have first learned about these processes in the sixth grade.

As heat is transferred to a system (object), the temperature of the system (object) may increase. Substances vary in the amount of heat necessary to raise their temperatures by a given amount. More mass in the system clearly requires more heat for a given temperature change. An expression that illustrates the relationship between the amount of heat transferred and the corresponding temperature change is shown in equation (24). The change in temperature ΔT is proportional to the amount of heat added. This relationship is specified by

$$Q = mC\Delta T, \qquad \text{(eq. 24)}$$

where Q is the internal energy added by heat transfer to the system from the surroundings, ΔT is the difference in temperature between the final and initial states of the system, m is the system's mass, and C is the specific heat of the substance (in joules/gram-°C or calories/gram-°C). *Specific heat* is a characteristic property of a material. The unit of specific heat is energy divided by mass and temperature change (e.g., calories/gram-degree).

Water, which serves as a standard against which all other materials may be compared, has a specific heat of one calorie/gram-degree. In other words, one calorie of heat is required to raise one gram of water one degree Celsius. When a gram of water cools one degree, one calorie is liberated. This value is large compared with those of other substances. Therefore, it takes much more heat to warm water than it does to raise the temperature of the same amount of most other substances. This fact has important implications for weather and climate and is one reason the weather is "tempered" in coastal areas (e.g., summers are cooler and winters are warmer than they are in inland areas at a similar latitude).

Equation (24) makes the distinction between heat and temperature quite clear. It specifies that heat can flow in or out of a system because of temperature difference alone. There are, however, other situations in which the addition or removal of heat is not accompanied by changes in temperature. These situations occur when a substance undergoes a change of phase, or state, such as when water evaporates or freezes. During phase changes, the absorption or release of heat takes place while the system remains at a constant temperature. For example, when ice melts in a glass of water that is sufficiently well mixed, the temperature of the water remains at the freezing point of water. Additional heating of the water raises its temperature only after the ice has melted.

3. b. *Students know* that the work done by a heat engine that is working in a cycle is the difference between the heat flow into the engine at high temperature and the heat flow out at a lower temperature (first law of thermodynamics) and that this is an example of the law of conservation of energy.

The total energy of an isolated system is the sum of the kinetic, potential, and thermal energies. A system is isolated when the boundary between the system and the surroundings is clearly defined. Total energy is conserved in all classical processes. Thus, the law of conservation of energy can be restated as the first law of thermodynamics; that is, for a closed system the change in the internal energy ΔU is given by the expression

$$\Delta U = Q - W, \qquad \text{(eq. 25)}$$

where Q is the internal energy added by heat transfer to the system from the surroundings and W is the work done by the system. The quantities ΔU, Q, and W in equation (25) can be negative or positive, depending on whether energy is converted from mechanical form into heat, as when work is done on the system, or on whether heat is transformed into mechanical energy, as when the system is doing work. By convention, Q is positive for heat added to the system and negative for heat transferred to the surroundings, and W is positive for work done by the system and negative for work done on the system. As a practical matter, energy that cannot be obtained as work is considered a loss to the system. Thus, the first law of thermodynamics indicates how much energy is available to do work.

A heat engine is a device for getting useful mechanical work from thermal energy. While part of the input heat energy Q_H, sometimes known as *heat of combustion,* is converted into useful work W, the remaining heat is lost to the environment as exhaust heat Q_L. That is, the work done by a heat engine is the difference between thermal energy flowing in at higher temperature and heat flowing out at lower temperature, as shown in the following equation:

$$W = Q_H - Q_L. \qquad \text{(eq. 26)}$$

This simple relationship is valid for an idealized engine, also called a *Carnot engine.*

3. c. *Students know* the internal energy of an object includes the energy of random motion of the object's atoms and molecules, often referred to as *thermal energy.* The greater the temperature of the object, the greater the energy of motion of the atoms and molecules that make up the object.

The internal energy of objects is in the motion of their atoms and molecules and in the energy of the electrons in the atoms. For ideal gases, nearly realized by air molecules, heat transferred to the gas increases the average speed of the gas molecules. The higher the temperature, the greater the average speed. If it were possible to observe the motion of molecules in a gas at a fixed temperature, one would see molecules with different masses moving on average at different speeds. More massive molecules, for example, move more slowly because the average kinetic energy of each type of molecule is the same in the gas, and the kinetic energy is proportional to the product of the mass and the square of the velocity of the gas molecules. The pressure of a gas results from individual molecules bumping against containing walls and other objects. Each hit and change of direction causes a change in momentum and therefore a net force or push on the object hit. One molecule's contribution to total pressure is very small, but measurable pressures result when large numbers of fast-moving atoms or molecules participate in these collisions.

For an ideal gas system at thermal equilibrium, the kinetic energy of an individual gas molecule averaged over time is

$$E = \tfrac{3}{2}kT, \qquad \text{(eq. 27)}$$

where $k = 1.38 \times 10^{-23}$ joule/K, and T is the absolute temperature in Kelvin (K). The Kelvin temperature scale and its conversion to the customary Fahrenheit and Celsius scales are discussed in standards 4.d and 4.e in the chemistry section in this chapter.

3. d. *Students know* that most processes tend to decrease the order of a system over time and that energy levels are eventually distributed uniformly.

Energy in the form of heat transfers from hot to cold, but not from cold to hot, regardless of whether that energy transfers by radiation, conduction, or convection. Why? Matter exists in discrete energy states (or levels). For tiny objects, such as a single electron, the difference in energy between one state and the next is big enough to be detected and measured. For the larger objects of everyday experience, such as a pebble, the difference is too small to detect; still, the discrete states exist, and it makes sense to speak of the probability with which any given system is to be found in any one of its possible states.

A system of many components has many states of given total energy because some components can have a larger fraction of that energy if others have less. Such a system evolves so that all states with the same total energy become equally probable. Heat flows from hot to cold because states in which components share energy equally vastly outnumber states in which they do not. A copper bar with one end hot and the other cold has many atoms with more kinetic energy on the hot end and many atoms with less kinetic energy on the cold end. Later, however, because the kinetic energy has been transferred from the hot end of the bar to the cold end, all the atoms will have nearly the same kinetic energy. The change can be interpreted as heat flowing from hot to cold until the temperature of the bar is uniform. Similarly, most physical processes disorder a system because disordered states vastly outnumber ordered ones. A drop of perfume evaporates because states in which molecules of perfume are scattered throughout a large volume of air vastly outnumber states in which the molecules are confined in the tiny volume of a drop.

3. e. *Students know* that entropy is a quantity that measures the order or disorder of a system and that this quantity is larger for a more disordered system.

Students know from Standard 3.d that energy transferred as heat leads to the redistribution of energy among energy levels in the substances that compose the system. This redistribution increases the disorder of material substances. A quantity called *entropy* has been defined to track this process and to measure the randomness, or disorder, of a system. Entropy is larger for a disordered system than for an ordered one. Thus, a positive change in entropy, in which the final entropy is larger than the initial entropy, indicates decreasing order, also considered as increasing disorder. The properties of entropy fix the maximum efficiency with which energy stored as a temperature difference can be converted into work.

For a system at constant temperature, such as during melting or boiling, the change in entropy ΔS is given by

$$\Delta S = Q/T\,, \qquad \text{(eq. 28)}$$

where Q is the heat (thermal energy) that flows into or out of the system and T is the absolute temperature. The units of entropy are joules/K. All processes that require energy, for example, biochemical reactions that support life, occur only because the entropy increases as a result of the process.

3. f.* *Students know* the statement "Entropy tends to increase" is a law of statistical probability that governs all closed systems (second law of thermodynamics).

The second law of thermodynamics states that all spontaneous processes lead to a state of greater disorder. When an ice cube melts and the water around it becomes cooler, for example, the internal energy of the ice-water system becomes more uniformly spread, or more disordered. Most processes in nature are irreversible because they move toward a state of greater disorder. A broken egg, for instance, is almost impossible to restore to its original ordered state.

Another statement of the second law of thermodynamics is that in a closed system all states tend to become equally probable. Calculating the statistical probability of a condition involves counting all the ways to distribute energy in a system, and that procedure involves mathematics that is more complex than most students will have mastered. However, most students can recognize that there are many more ways to distribute energy approximately evenly within a system than there are ways to have energy concentrated. As spontaneous processes make all ways equally probable, a system thus becomes more likely to be found with its energy distributed than concentrated, and so the system becomes disordered.

Students who complete these standards will have learned the first and second laws of thermodynamics. They should understand that when physical change occurs, energy must be conserved, and some of this energy cannot be recovered for useful work because it has added to the disorder of the universe.

3. g.* *Students know* how to solve problems involving heat flow, work, and efficiency in a heat engine and know that all real engines lose some heat to their surroundings.

As implied in Standard 3.b, when heat flows from a body at high temperature to one at low temperature, some of the heat can be transformed into mechanical work. This principle is the basic concept of the heat engine. The remainder of the heat is transferred to the surroundings and therefore is no longer available to the system to do work. This transferred heat is never zero; therefore, some heat must always be transferred to the surroundings. Examples of practical heat engines are steam engines and internal combustion engines. Steam at a high temperature T_H pushes on a piston or on a turbine and does work. Steam at a lower temperature T_L is then drawn off from the engine into the air. When an idealized (i.e., reversible) engine completes a cycle, the change in entropy is zero. Equation (28) shows that

$$Q_H/T_H = Q_L/T_L \, . \qquad \text{(eq. 29)}$$

When this relation is combined with the conservation law of equation (26), the maximum possible efficiency, denoted as “eff,” can be calculated as

$$\text{eff (\%)} = 100 \times W/Q_H = 100 \times (T_H - T_L)/T_H, \qquad \text{(eq. 30)}$$

where efficiency is the ratio of work done by the engine to the heat supplied to the engine. The efficiency of converting heat to work is proportional to the difference between the high and low temperatures of the engine’s working fluids, usually gases. For a Carnot engine to be 100 percent efficient, the temperature of the exhaust heat needs to be absolute zero, an impossible occurrence.

STANDARD SET 4. Waves

Students can be introduced to this standard set by learning to distinguish between mechanical and electromagnetic waves. In general, a *wave* is defined as the propagation of a disturbance. The nature of the disturbance may be mechanical or electromagnetic. Mechanical waves, such as ocean waves, acoustic waves, seismic waves, and the waves that ripple down a flag stretched taut by a wind, require a medium for their propagation and gradually lose energy to that medium as they travel. Electromagnetic waves can travel in a vacuum and lose no energy even over great distances. When electromagnetic waves travel through a medium, they lose energy by absorption, a phenomenon that explains why light signals sent through the most transparent of optical fibers still need to be amplified and repeated. In contrast, light emitted from distant galaxies has traveled great distances without the aid of amplification, an indication that a relatively small amount of material is in the light's path.

Waves transfer energy from one place to another without net circulation or displacement of matter. Light, sound, and heat energy can be transmitted by waves across distances measured from fractions of a centimeter to many millions of kilometers. Exertion of a direct mechanical force, such as a push or a pull, on a physical body is an example of energy transfer by direct contact. However, for transfer to occur, objects do not need to be in direct physical contact with a source of energy. For instance, light transmits from a distant star, heat radiates from a fire, and sound propagates from distant thunder. Energy may be transferred by radiation, for example, from the Sun to Earth; therefore, radiation is also an example of a noncontact energy transfer. Both sight and hearing are senses that can perceive energy patterned to convey information without direct contact between the source and the sensing organ.

If students take physics before they have studied other high school science courses, the teacher may find it useful to cross-reference materials on pressure, heat, and solar radiation from the following standards in this chapter: 4.a and 7.a in the chemistry section and 4.a through 4.c in the earth sciences section. Algebra, geometry, and simple trigonometric skills are required for some of the advanced topics in this standard set. Students with a good foundation in algebra and geometry can be taught the trigonometry necessary to solve problems in this standard set.

4. Waves have characteristic properties that do not depend on the type of wave. As a basis for understanding this concept:

a. *Students know* waves carry energy from one place to another.

Waves may transport energy through a vacuum or through matter. Light waves, for example, transport energy in both fashions, but sound waves and most other waves occur only in matter. However, even waves propagating through matter transport energy without any net movement of the matter, thus differing from other means of energy transport, such as convection, a waterfall, or even a thrown object.

4. b. *Students know* how to identify transverse and longitudinal waves in mechanical media, such as springs and ropes, and on the earth (seismic waves).

Waves that propagate in mechanical media are either longitudinal or transverse waves. The disturbance in longitudinal waves is parallel to the direction of propagation and causes compression and expansion (rarefaction) in the medium carrying the wave. The disturbance in transverse waves is perpendicular to the direction of propagation of the wave. Examples of longitudinal waves are sound waves and *P*-type earthquake waves. In transverse waves a conducting medium, or a test particle inserted in the wave, moves perpendicular to the direction in which the wave propagates. Examples of transverse waves are *S*-type earthquake waves and electromagnetic (or light) waves.

4. c. *Students know* how to solve problems involving wavelength, frequency, and wave speed.

All waves have a velocity $\mathbf{v}$ (propagation speed and direction), a property that represents the rate at which the wave travels. Only periodic, sustained waves can be easily characterized through the properties of wavelength and frequency. However, most real waves are *composite,* meaning they can be understood as the sum of a few or of many waveforms, each with an amplitude, a wavelength, and a frequency.

Wavelength λ is the distance between any two repeating points on a periodic wave (e.g., between two successive crests or troughs in a transverse wave or between adjacent compressions or expansions [rarefactions] in a longitudinal wave). Wavelength is measured in units of length.

Frequency f is the number of wavelengths that pass any point in space per second. A wave will make any particle it encounters move in regular cycles, and frequency is also the number of such cycles made per second and is often abbreviated as cycles per second. The unit of frequency is the inverse second (s^{-1}), a unit also called the hertz (Hz).

Periodic wave characteristics are related to each other. For example,

$$v = f\lambda . \qquad \text{(eq. 31)}$$

4. d. *Students know* sound is a longitudinal wave whose speed depends on the properties of the medium in which it propagates.

Sound waves, sometimes called *acoustic waves,* are typically produced when a vibrating object is in contact with an elastic medium, which may be a solid, a liquid, or a gas. A sound wave is longitudinal, consisting of regions of high and low pressure (and therefore of compression and rarefaction) that propagate away from the source. (Note that sound cannot travel through a vacuum.) In perceiving sound, the human eardrum vibrates in response to the pattern of high and low pressure. This vibration is translated into a signal transmitted by the nervous system to the brain and interpreted by the brain as the familiar sensation of sound. Microphones similarly translate vibrations into electrical current. Sound speakers reverse the process and change electrical signals into vibrational motion, recreating sound waves.

An acoustic wave attenuates, or reduces in amplitude, with distance because the energy in the wave is typically spread over a spherical shell of ever-increasing area and because interparticle friction in the medium gradually transforms the wave's energy into heat. The speed of sound varies from one medium to another, depending primarily on the density and elastic properties of the medium. The speed of sound is typically greater in solid and liquid media than it is in gases.

4. e. *Students know* radio waves, light, and X-rays are different wavelength bands in the spectrum of electromagnetic waves whose speed in a vacuum is approximately 3×10^8 m/s (186,000 miles/second).

Electromagnetic waves consist of changing electric and magnetic fields. Because these fields are always perpendicular to the direction in which a wave moves, an electromagnetic wave is a transverse wave. The electric and magnetic fields are also always perpendicular to each other. Concepts of electric and magnetic fields are introduced in Standard Set 5, "Electric and Magnetic Phenomena," in this section. The range of wavelengths for electromagnetic waves is very large, from less than nanometers (nm) for X-rays to more than kilometers for radio waves. The human eye senses only the narrow range of the electromagnetic spectrum from 400 nm to 700 nm. This range generates the sensation of the rainbow of colors from violet through the respective colors to red. In a vacuum all electromagnetic waves travel at the same speed of 3×10^8 m/s (or 186,000 miles per second). In a medium the speed of an electromagnetic wave depends on the medium's properties and on the frequency of the wave. The ratio of the speed of a wave of a given frequency in a vacuum to its speed in a medium is called that medium's *index of refraction.* For visible light in water, this number is approximately 1.33.

4. f. *Students know* how to identify the characteristic properties of waves: interference (beats), diffraction, refraction, Doppler effect, and polarization.

A characteristic and unique property of waves is that two or more can occupy the same region of space at the same time. At a particular instant, the crest of one wave can overlap the crest of another, giving a larger displacement of the medium from its condition of equilibrium *(constructive interference);* or the crest of one wave can overlap the trough of another, giving a smaller displacement *(destructive interference).* The effect of two or more waves on a test particle is that the net force on the particle is the algebraic sum of the forces exerted by the various waves acting at that point.

If two overlapping waves traveling in opposite directions have the same frequency, the result is a standing wave. There is a persistent pattern of having no displacement in some places, called *nulls* or *nodes,* and large, oscillating displacements in others, called *maxima* or *antinodes.* If two overlapping waves have nearly the same frequency, a node will slowly change to a maximum and back to a node, and a maximum will slowly change to a node and back to a maximum. For sound waves this periodic change leads to audible, periodic changes from loud to soft, known as *beats.*

Diffraction describes the constructive and destructive patterns of waves created at the edges of objects. Diffraction can cause waves to bend around an obstacle or to spread as they pass through an aperture. The nature of the diffraction patterns of a wave interacting with an object depends on the ratio of the size of the obstacle to the wavelength. If this ratio is large, the shadows are nearly sharp; if it is small, the shadows may be fuzzy or not appear at all. Therefore, a hand can block a ray of light, whose average wavelength is about 500 nm, but cannot block an audible sound, whose average wavelength is about 100 cm. The bending of water waves around a post and the diffraction of light waves when passing through a slit in a screen are examples of diffraction patterns.

Refraction describes a change in the direction of a wave that occurs when the wave encounters a boundary between one medium and another provided that the media have either different wave velocities or indexes of refraction and provided that the wave arrives at some angle to the boundary other than perpendicular. At a sharp boundary, the change in direction is abrupt; however, if the transition from one medium to another is gradual, so that the velocity of the wave changes slowly, then the change in the wave's direction is also gradual. Therefore, a ray of light that passes obliquely from air to water changes its direction at the water's surface, but a ray that travels through air that has a temperature gradient will follow a bent path. A ray of light passing through a saturated solution of sugar (sucrose) and water, which has an index of refraction of 1.49, will not change direction appreciably on entering a colorless, transparent piece of quartz submersed in the solution because the quartz has an almost identical index of 1.51. The match in indexes makes the quartz nearly invisible in the sugar-water solution.

Another interesting phenomenon, the *Doppler effect,* accounts for the shift in the frequency of a wave when a wave source and an observer are in motion relative to each other compared with when they are at relative rest. This effect is most easily understood when the source is at rest in some medium and the observer is approaching the source at constant speed. The interval in time between each successive wave crest is shorter than it would be if the observer were at rest, and so the frequency observed is larger. The general rule, for observers moving at velocities much less than the velocity of the wave in its medium, is that the change in frequency depends only on the velocity of the observer relative to the source. Therefore, the shriek of an ambulance siren has a higher pitch when the source approaches and a lower pitch when the source recedes. For an observer following the ambulance at the same speed, the siren would sound normal. Similar shifts are observed for visible light.

Polarization is a property of light and of other transverse waves. *Transverse waves* are those in which the displacement of a test particle is always perpendicular to the direction in which the wave travels. When that displacement is always parallel to a particular direction, the wave is said to be *(linearly) polarized.* A ray of light emitted from a hot object, like a lamp filament or the sun, is unpolarized; such a ray consists of many component waves overlapped so that there is no special direction perpendicular to the ray in which a test particle is favored to move. The components of an unpolarized ray can be sorted to select such a special direction and so make one or more polarized rays. An unpolarized ray that is partly reflected and partly transmitted by an angled sheet of glass is split into rays that are polarized; an unpolarized ray can become polarized by going through a material that allows only waves corresponding to one special direction to pass through. Polarized sunglasses and stretched cellophane wrap are examples of polarizing materials.

STANDARD SET 5. Electric and Magnetic Phenomena

The electromagnetic force is one of only four fundamental forces; the others are the gravitational force and the forces that govern the strong and weak nuclear interactions. Electric and magnetic phenomena are well understood by scientists, and the unifying theory of the electromagnetic force is one of the great successes of science. The electromagnetic force accounts for the structure and for the unique chemical and physical properties of atoms and molecules. This force binds atoms and molecules and largely accounts for the properties of matter. Photons convey this force and electromagnetic energy.

Using electromagnetism for practical technological applications is taken for granted in modern society. Many devices of daily life, such as household appliances, computers, and equipment for communication, entertainment, and transportation, were developed from electromagnetic phenomena. Understanding the fundamental ideas of electricity and magnetism is basic to achieving success in a vast array of endeavors, from auto mechanics to nuclear physics.

Electricity and magnetism are now known to be two manifestations of a single phenomenon, the electromagnetic force. The originally separate theories explaining electricity and magnetism have been combined into a single theory of electromagnetism, whose predictive power is greater than that of either of the two previous, separate theories. The joining of these theories into a common mathematical framework is an example of how seemingly disparate phenomena can sometimes be unified in physics.

Studies of electric and magnetic phenomena build directly on the high school physics standards presented earlier and require a thorough understanding of the concepts of motion, forces, and conservation of energy. The subject of energy transport by waves is also important. Students in the lower grade levels are introduced to electricity as they learn that electric current can carry energy from one place to another. They also learn about light and the relationship between electricity and magnetism. To understand the concepts in Standard Set 5, students will need a strong grasp of beginning algebra and geometry. Basic trigonometry is also required for some of the advanced topics. Several topics covered in the lower grade levels may need to be reviewed as a part of teaching this standard set, particularly during the transition to standards-based education. In particular, the following facts are pertinent: (1) charge occurs in definite, discrete amounts; (2) charge comes in two varieties: positive and negative; and (3) the smallest amount of observable charge is the charge on an electron (or a proton).

Students should be acquainted with Newton's law of gravitation from standards studied previously (see Standard 1.e for grade two and Standard 4.c for grade five in Chapter 3 and standards 2.g and 4.e for grade eight in Chapter 4). Both Newton's law and Coulomb's law describe forces that diminish as the square of distance, and it may be helpful to compare those forces as a part of teaching some of the standards (see standards 1.e and 1.m* in this section). However, the comparison should be done with attention to the fundamental differences between the two types of forces, and certain points must be clearly understood to avoid sowing misconceptions. For example:

- Only the difference in electric or gravitational potential between two points has physical significance; the value of the potential at a particular point can be defined only relative to some reference point.
- The direction of an electric current is defined as the same as the direction of motion of charge carriers, conventionally assumed to be positive, although the charge carriers (the electrons) in wires are in fact negative. Therefore the direction of the electric current in wires is opposite to the direction of motion of the charge carriers.
- A *direct current* (DC) flows in one direction only, and an *alternating current* (AC) reverses at regular intervals.
- Ohm's law applies to conducting material under the assumption that resistance is independent of the magnitude and polarity of the potential difference (or of the applied electric field) across the material. The formulas used in Ohm's law to calculate an unknown amount of current, voltage, or resistance are $I = V/R$, $V = IR$, and $R = V/I$.

It may be helpful to describe *electric potential* as a measure of the tendency of a charged body to move from one point to another in an electrostatic field in the same way that *gravitational potential* is a measure of a body with mass to move from one point to another in a gravitational field. In both fields the work done to move the body does not depend on the path taken between the points but can be computed from the difference in the potential at the points.

As students solve simple circuit problems for this standard, they will also need to know the schematic representations of the various circuit elements, including a battery, a resistor, and a capacitor.

5. Electric and magnetic phenomena are related and have many practical applications. As a basis for understanding this concept:

a. *Students know* how to predict the voltage or current in simple direct current (DC) electric circuits constructed from batteries, wires, resistors, and capacitors.

Electric current I is the flow of net charge, and a complete, continuous path of current is called an *electric circuit.* If the charge carriers are positive, the electric current flows in the direction the carriers move; but if the carriers are negative, as they are in ordinary wires, the electric current flows in the opposite direction. Wires that carry currents are usually made of highly conducting metals, such as copper. If net charge q passes by a point a in a conducting wire in time t, the current I_a at that point is

$$I_a = q/t \,. \qquad \text{(eq. 32)}$$

In the case of uniform current I, the rate of charge flow is the same through the entire length of the wire. Current is measured in units of amperes (A), which are equal to coulombs/second (A = C/s), the logical consequence of equation (32).

A particle with a charge q placed in an electric field will be subject to electrostatic forces and will have a potential energy. Moving the charge will change its potential energy from some value PE_a to PE_b, reflecting the work W_{ba} done by the electric field (see Standard 2.a in this section). Potential energy depends also on the magnitude of the charge being transported. A more convenient quantity is the potential energy per unit charge, which has a unique value at any point, independent of the actual charge of the particle in the electric field. This quantity is called *electric potential,* or just *potential,* and the difference V_{ab} between the potentials at two points a and b is the *voltage.* By this definition, voltage provides a measure of the work per unit charge required to move the charge between two points a and b in the field; alternatively, it represents the corresponding difference in potential energy per unit charge. This principle is expressed as

$$V_{ab} = V_a - V_b = W_{ba}/q = PE_a/q - PE_b/q \,. \qquad \text{(eq. 33)}$$

Electric potential and voltage are measured in units of volt (V), which, as required by the preceding definition, is equal to joules per coulomb (J/C).

For a current-carrying wire, the potential difference between two points along the wire causes the current to flow in that segment.

5. b. *Students know* how to solve problems involving Ohm's law.

Resistance, measured in ohms, of a conducting medium (conductor) is the opposition offered by the conductor to the flow of electric charge. A potential difference V is required to cause electrons to move continuously. Ohm's law gives the relationship between the current I that results when a voltage V is applied across a wire with resistance R. This law is expressed as

$$I = V/R \,. \qquad \text{(eq. 34)}$$

Capacitors, which are devices for storing electrical charge, generally consist of two conductors with a potential difference that are separated by an insulator. A typical capacitor consists of two parallel metal plates insulated from each other by a *dielectric,* a material that does not conduct electricity. Capacitance *C,* the ability of a capacitor to store electric charge, can be measured in units of farads. The capacitance can be found from the following relation:

$$C = q/V, \qquad \text{(eq. 35)}$$

where q is the charge stored ($+q$ on one plate and $-q$ on the other) and V is the potential difference between the conducting surfaces. Based on equation (35), the unit of farad is defined as coulomb/volt (C/V).

5. c. *Students know* any resistive element in a DC circuit dissipates energy, which heats the resistor. Students can calculate the power (rate of energy dissipation) in any resistive circuit element by using the formula Power = IR (potential difference) × I (current) = I^2R.

Electric power P is defined as the rate of dissipation of electric energy, or the rate of production of heat energy, in a resistor and is given by Joule's law, in which

$$P = IV. \qquad \text{(eq. 36)}$$

Through the use of Ohm's law, this equation can also be written as $P = I^2R$ or $P = V^2/R$. Power is measured in watts, where 1 watt = 1 ampere-volt (W = A-V) = 1 joule/second.

Dissipation of energy as heat is a consequence of electrical resistance. In other words *electric power* is equivalent to the work per second that must be done to maintain an electric current. Alternatively, *power* is the rate at which electrical energy is transferred from the source to other parts of the circuit. The unit of kilowatt hour (kWH) is sometimes used commercially to represent energy production and consumption, where 1 kWH = 3.6×10^6 J.

5. d. *Students know* the properties of transistors and the role of transistors in electric circuits.

Semiconductors are materials with an energy barrier such that only electrons with energy above a certain amount can "flow." As the temperature rises, more electrons are free to move through these materials. A transistor is made of a combination of differently "doped" materials arranged in a special way. Transistors can be used to control large current output with a small bias voltage. A common role of transistors in electric circuits is that of amplifiers. In that role transistors have almost entirely replaced vacuum tubes that were widely used in early radios, television sets, and computers.

5. e. *Students know* charged particles are sources of electric fields and are subject to the forces of the electric fields from other charges.

Electrostatic force represents an interaction across space between two charged bodies. The magnitude of the force is expressed by a relationship similar to that for the gravitational force between two bodies with mass. For both gravity and electricity, the force varies inversely as the square of the distance between the two bodies. For two charges q_1 and q_2 separated by a distance r, the relationship is called Coulomb's law,

$$F = kq_1q_2/r^2 , \qquad \text{(eq. 37)}$$

where k is a constant. Customary units for charge are coulombs (C), in which case $k = 9 \times 10^9 \text{Nm}^2/\text{C}^2$.

An electric field is a condition produced in space by the presence of charges. A field is said to exist in a region of space if a force can be measured on a test charge in the region. Many different and complicated distributions of electric charge can produce the same simple motion of a test charge and therefore the same simple field; for that reason it is usually easier to study first the effect of a model field on a test charge and to consider only later what distribution of other charges might produce that field.

5. f. *Students know* magnetic materials and electric currents (moving electric charges) are sources of magnetic fields and are subject to forces arising from the magnetic fields of other sources.

A magnetic force exists between magnets or current-carrying conductors or both. A stationary charge does not produce magnetic forces. Furthermore, no evidence for the existence of magnetic monopoles, which would be the magnetic equivalent of electric charges, has yet been found. Iron and other materials that can be magnetized have domains in which the combined motion of electrons produces the equivalent of small magnets in the metal. When many of these domains are aligned, the entire metal object becomes a strong magnet. Therefore, to the best of scientific knowledge, all magnetic effects result from the motion of electrical charges.

The concept of a field applies to magnetism just as it does to electricity (see Standard 5.e in this section). Magnetic fields are generated either by magnetic materials or by electric currents caused by the motion of charged particles. A standard unit for the magnetic field strength is the Tesla (T). Electric charges moving through a magnetic field experience a magnetic force. The direction of the magnetic force is always perpendicular to the line of motion of the electric charges. The force is at maximum when the direction of motion of the electric charges (their velocity vector) is perpendicular to the magnetic field and at zero when the two are parallel.

5. g. *Students know* how to determine the direction of a magnetic field produced by a current flowing in a straight wire or in a coil.

The direction of a magnetic field is by convention taken to be outward from a north pole and inward from a south pole. The right-hand rule finds the direction of the magnetic field produced by a current flowing in a wire or coil. To find the direction in a wire, a student wraps the fingers of the right hand around the wire with the thumb pointing in the direction in which the electric current flows (in a wire electrons and electric current move in opposite directions). The fingers encircling the wire then point in the direction of the magnetic field outside the wire. The same rule will find the direction of the magnetic field inside a coil if one imagines that the right hand wraps around a wire that forms one of the loops that make up the coil. A different rule using the right hand also works for coils. The coil is held in the palm of the right hand with the fingers wrapped around the coil and pointing in the direction in which the electric current flows through the loops. The thumb then points in the direction of the magnetic field inside the coil.

5. h. *Students know* changing magnetic fields produce electric fields, thereby inducing currents in nearby conductors.

The concept of electromagnetic induction is based on the observation that changing magnetic fields create electric fields, just as changing electric fields are sources of magnetic fields. In a conductor these induced electric fields can drive a current. The direction of the induced current is always such as to oppose the changing magnetic field that caused it. This principle is called Lenz's law.

5. i. *Students know* plasmas, the fourth state of matter, contain ions or free electrons or both and conduct electricity.

A *plasma* is a mixture of positive ions and free electrons that is electrically neutral on the whole but that can conduct electricity. A plasma can be created by very high temperatures when molecules disassociate and their constituent atoms further break up into positively charged ions and negatively charged electrons. Much of the matter in the universe is in stars in the form of plasma, a mixture of electrified fragments of atoms. Plasma is considered a fourth state of matter, as fundamental as solid, liquid, and gas.

5. j.* *Students know* electric and magnetic fields contain energy and act as vector force fields.

Both the electric field **E** and the magnetic field **B** are vector fields; therefore, they have a magnitude and a direction. The fields from matter whose distributions in space and in velocity do not change with time are easy to visualize; for example, charges fixed in space, steady electric currents in wires, or permanent magnets. Electric fields from matter like this are generally represented by "lines of force" that start on positive charges and end on negative charges but never form closed loops (see Standard 5.m*, which appears later in this section). In contrast, the lines for magnetic fields always form closed loops; they never start and end—magnetic field lines do not have terminal points. Even the magnetic field lines around simple bar magnets, which are typically drawn as emanating from the north pole and entering the south pole, in fact continue through the body of the magnet to form closed loops.

The reason magnetic fields form loops while electric fields do not has to do with their different sources in matter at rest. Electric fields come from point charges, and magnetic fields come from point dipoles, which are more complicated; no sources of magnetic field with the simple properties of charge—that is, no magnetic monopoles—are known to exist. The direction in which an electric field points along a line of force is away from positive charge and toward negative charge; the direction in which a magnetic field (that is due to a current) points along a closed loop can be found by the right-hand rule (see Standard 5.g, which appears earlier in this section).

Electric and magnetic fields are associated with the existence of potential energy. The fields are usually said to *contain* energy. For example, the potential energy of a system of two charges q_1 and q_2 located a distance r apart, is given by

$$PE = kq_1q_2/r\,. \qquad \text{(eq. 38)}$$

In general, the potential energy of a system of fixed-point charges is defined as the work required to assemble the system bringing each charge in from an infinite distance.

5. k.* *Students know* the force on a charged particle in an electric field is $q\mathbf{E}$, where $\mathbf{E}$ is the electric field at the position of the particle and q is the charge of the particle.

The electric field strength $\mathbf{E}$ at a given point is defined as the force experienced by a unit positive charge, $\mathbf{E} = \mathbf{F}/q$. The units of $\mathbf{E}$ are newton/coulomb (N/C). By this definition the force experienced by a charged particle is

$$\mathbf{F} = q\mathbf{E}\,, \qquad \text{(eq. 39)}$$

where q is the magnitude of the particle's charge in coulombs and $\mathbf{E}$ is the electric field at the position of the charged particle.

5. l.* *Students know* how to calculate the electric field resulting from a point charge.

Coulomb's law is used in calculating the electric field caused by a point charge. According to equation (39), $\mathbf{E} = \mathbf{F}/q$, the magnitude of the field produced by a point charge q_1 is found by substituting equation (37) for $\mathbf{F}$ and dividing by the magnitude of the positive test charge q_2, which gives

$$E = kq_1/r^2. \qquad \text{(eq. 40)}$$

The direction of **E** is determined by the type of the source charge q_1, so that the vector is away from the positive charge (+) and toward the negative charge (–). (Remember that by definition the *field strength* is the force per unit of positive test charge.)

5. m.* *Students know* static electric fields have as their source some arrangement of electric charges.

The existence of a static electric field in a region of space implies a distribution of charges as the source. Conversely, any set of charges or charged surfaces sets up an electric field in the space around the charge. The customary first step in visualizing an electric field is to draw smooth curves, each of which contains only points of equal electric potential. Electric field lines ("lines of force") can then be drawn as curves that are everywhere perpendicular to the curves of equal potential. Electric field lines are assigned a direction that runs from regions of high potential to low and, therefore, from positive point charges to negative ones. The lines of force represent the path a particle with a small positive charge would take if released in the field.

The method used in deriving equation (40) can be used, in principle, to determine the field produced from any distribution of charges. At each point a net vector **E** is obtained by summing the vector contributions from each charge. This process can be readily done for a two-charge system in which the geometry is relatively simple. For more complicated distributions the methods of calculus are generally required to obtain the field.

5. n.* *Students know* the magnitude of the force on a moving particle (with charge *q*) in a magnetic field is *qvB* sin(*a*), where *a* is the angle between ***v*** and ***B*** (*v* and *B* are the magnitudes of vectors ***v*** and ***B***, respectively), and students use the right-hand rule to find the direction of this force.

The force on a moving particle of charge q traveling at velocity v in a magnetic field B is given by

$$F = qvB \sin(a) \, , \qquad \text{(eq. 41)}$$

where a is the angle between the direction of the motion of the charged particle and the direction of the magnetic field. (If $a = 0$, then the particle is traveling parallel to the direction of the field and the magnetic force on it is zero.) The maximum force is obtained when the particle is traveling perpendicular to the magnetic field. Students can determine the direction of the magnetic force through the use of the right-hand rule. The magnetic force is perpendicular to both the direction of motion of the charge and to the direction of the magnetic field. Equation (41) shows that Tesla, a standard unit for the magnetic field mentioned previously, is equal to 1 N-s/C-m (see the discussion for Standard 5.f, which appears previously in this section).

5. o.* *Students know* how to apply the concepts of electrical and gravitational potential energy to solve problems involving conservation of energy.

In standards 2.a and 2.b in this section, students learned that if a stone is raised from Earth's surface, the work done against Earth's gravitational attraction is stored as potential energy in the system of stone plus Earth. If the stone is released, the stored potential energy is transformed into kinetic energy, which steadily increases as the stone moves faster toward Earth. Once the stone comes to rest, this kinetic energy will ultimately be transformed into thermal energy. A similar situation exists in electrostatics. If the separation between two opposite charges is increased, work must be performed. The work is positive if the charges are opposite and negative. The energy represented by this work can be thought of as stored in the system of charges as electric potential energy (see also Standard 5.j* in this section) and, like gravitational potential energy, may be transformed into other forms, such as kinetic and thermal energy.

A simple example is a charge q moving freely between point a and point b, with a potential difference V_{ab} between the two points. If q is positive, the change in electric potential energy can be found from equation (35) and is

$$\Delta PE = qV_{ab}\,. \qquad \text{(eq. 42)}$$

By conservation of energy a corresponding amount of the kinetic energy is acquired, or released, by the charge at point b such that

$$\Delta KE = \Delta PE = qV_{ab}\,. \qquad \text{(eq. 43)}$$

Through substitution of the standard expression $\frac{1}{2}mv^2$ for the kinetic energy, a variety of predictions can be made, assuming the accelerating potential does not result in velocities approaching the velocity of light. The final velocity v can be found if the charge q, the mass m, and the potential V are known. This method of imparting energy to charged particles is applied in such devices as television sets and in accelerators used in modern atomic and nuclear experiments.

Notes

1. *Science Content Standards for California Public Schools, Kindergarten Through Grade Twelve.* Sacramento: California Department of Education, 2000.
2. *Science Safety Handbook for California Public Schools.* Sacramento: California Department of Education, 1999.